PB80-181589

Soil Genesis, Hydrological Properties, Root Characteristics and Microbial Activity of 1-to 50-Year Old Stripmine Spoils

Montana Agricultural Experiment Station
Bozeman

Prepared for

Industrial Environmental Research
Lab.-Cincinnati, OH

Apr 79

U.S. Department of Commerce
National Technical Information Service
NTIS

USDA

United States
Department of
Agriculture

Science & Education Admin.
Cooperative Research
Washington DC 20250

CR 2

PB80-181589

EPA

United States
Environmental Protection
Agency

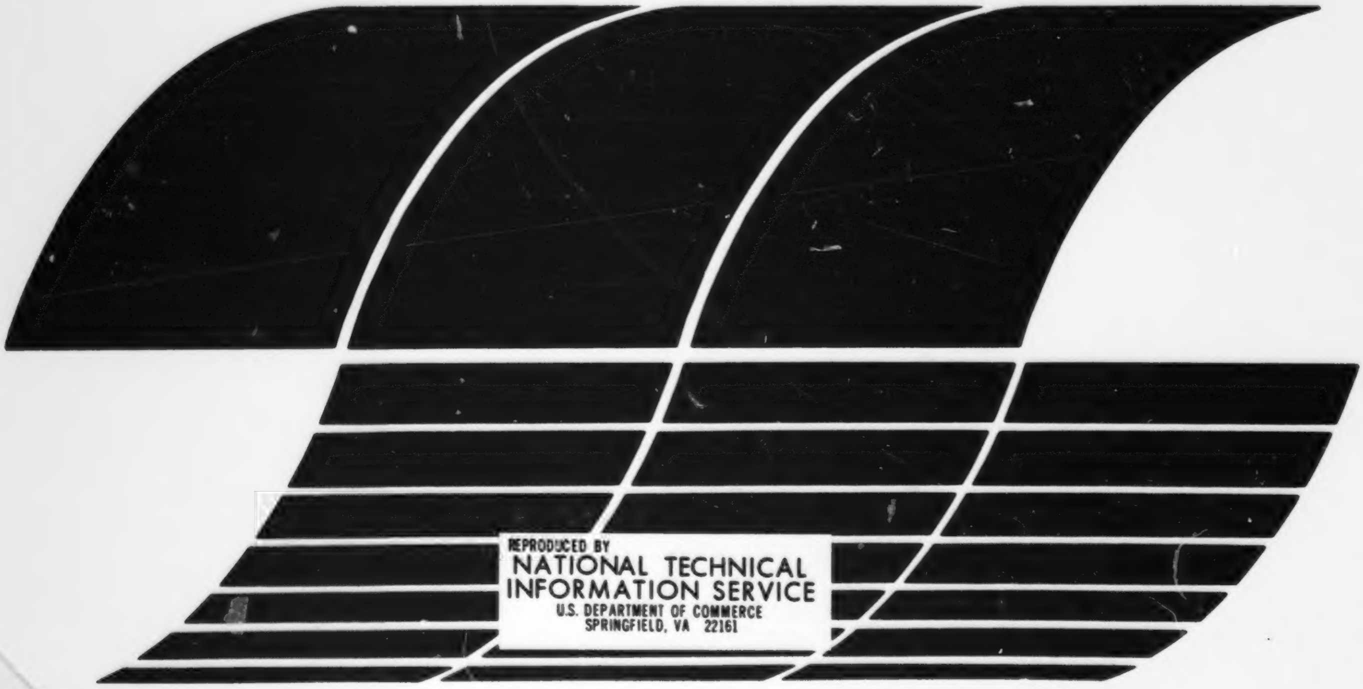
Industrial Environmental Research
Laboratory
Cincinnati OH 45268

EPA-600/7-79-100
April 1979

Research and Development

Soil Genesis, Hydrological Properties, Root Characteristics, and Microbial Activity of 1- to 50-Year Old Stripmine Spoils

Interagency Energy/Environment R&D Program Report



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TECHNICAL REPORT DATA

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1. REPORT NO. EPA-600/7-79-100	2.	3. RECIPIENT'S ACCESSION NO. PB80-181589
4. TITLE AND SUBTITLE SOIL GENESIS, HYDROLOGICAL PROPERTIES, ROOT CHARACTERISTICS AND MICROBIAL ACTIVITY OF 1- TO 50-YEAR OLD STRIPMINE SPOILS		5. REPORT DATE April 1979 issuing date 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) W. M. Schafer, G. A. Nielsen, D. J. Dollhopf, and K. Temple		8. PERFORMING ORGANIZATION REPORT NO. CR-2
9. PERFORMING ORGANIZATION NAME AND ADDRESS Montana Agricultural Experiment Station Reclamation Research Program Montana State University Bozeman, Montana 59717		10. PROGRAM ELEMENT NO. 1NE623 11. CONTRACT/GRANT NO. EPA-IAG D6-E762 SEA-CR 684-15-4
12. SPONSORING AGENCY NAME AND ADDRESS Industrial Environmental Research Lab. - Cinn, OH Office of Research and Development U. S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final 10/75 to 6/78 14. SPONSORING AGENCY CODE EPA/600/12

15. SUPPLEMENTARY NOTES

This project is part of the EPA-planned and coordinated Federal Interagency Energy/Environment R&D Program in cooperation with USDA, SEA-CR.

16. ABSTRACT

Reclamation of coal strip-mined land is a major environmental concern. The future of reclaimed land depends on the long-term stability of the soil-vegetation system on mined land. To evaluate some of the possible changes that occur in mine soils through time; soil genesis, water flow patterns, root development, and microbial activity were studied on natural soils and 1- to 50-year-old minesoils.

Similar soil development processes occur in both minesoils and natural soils, but because mine soils have a different origin, they will probably always remain different than natural soils. Differences in water flow patterns on minesoils and natural soils were attributed to plant community and soil textural differences. Roots extended to at least 2 m in mined and unmined soils but root distribution and root growth patterns varied from site to site as a result of differences in plant communities, soil temperature, and soil water content. Natural levels of microbiological activity were approached on most minesoils within three to five years after reclamation.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Soils Coal Coal Mines Spoil Hydrology Extraction Reclamation	Surface Mining Plants (botany) Soil Chemistry	Soil Genes Root Development Microbial Minesoils Montana	2A, 2D, 6M, 8H, 8M

18. DISTRIBUTION STATEMENT Release to the Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 232
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

☆ U. S. GOVERNMENT PRINTING OFFICE: 1979 — 657-060/5301

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EPA-600/7-79-100
April 1979

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SEA-CR IAG No. D6-E762

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This study was conducted in cooperation with the Science and Education Administration, Cooperative Research, USDA, Washington, DC 20250.

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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The views and conclusions contained in this report are those of the authors and should not be interpreted as representing the official policies or recommendations of the Science and Education Administration-Cooperative Research, U. S. Department of Agriculture.

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our enviornment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

Strip-mining for coal drastically alters the landscape of a limited number of acres in the Northern Great Plains each year. The cumulative effect of mining over many years may significantly alter the soil resources of this region. The Reclamation Research unit at Montana State University conducted a two-year study funded by the SEA-CR (USDA) and USEPA to 1) evaluate differences between native soils and soils on mined land and 2) study the changes in soil properties through time that occur on minesoils.

Soil chemical and physical properties were measured in 15 soils; 5 natural soils, 5 minesoils nearly 50 years old, and 5 minesoils less than 10 years old. Soil water movement patterns, soil temperature changes, root biomass, root uptake of radioactive phosphorus, and microbiological activity of all soils were monitored.

Results of this study are discussed in the following pages. Projections are made concerning soil development patterns, root growth rates, and microbiological activity as minesoils increase in age. Finally, recommendations on ways to improve reclamation techniques and increase mine soil potential are made. The results of this work should provide to the reclamation specialist of a mining company or control agency additional methods to establish good ground cover to minimize the environmental problem from surface mining. For further information contact the Extraction Technology Branch of the Resource Extraction and Handling Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

A sequence of soils on mined land, minesoils , 1 to 50 years in age were compared to many natural soils in southeastern Montana. The objective of this study was to evaluate the potential impact of mining on soil resources in the area, and to find what changes take place in minesoils through time that may affect soil potential.

Young minesoils constructed before passage of the 1973 Montana Strip-mine Reclamation Act were not as good as the best soils existing before mining. Minesoils were better than some of the poorer soils on the natural landscape, however. Minesoils currently being constructed in the Colstrip vicinity (in 1977 and 1978) appear to be better than minesoils studied in this report (constructed between 1970 and 1975). New minesoils (less than 10 years old) often support plant communities functionally more similar to native plant communities than old minesoils (50 years old). Modern reclamation techniques applied to suitable minesoils are more effective in reestablishing productive grassland communities than 50 years of succession on poor quality minesoils.

The natural processes which were active in the development of natural soils were found to occur in 50-year-old minesoils. Only a small amount of the change required to form the natural soils has taken place in minesoils, however. Only 50 years were required for organic matter content, and soil structure to reach levels common in natural soils in the top 5 cm of the soils. Up to 500 years may be required for organic matter and soil structure to reach equilibrium in deeper soil layers. As many as 10,000 years might be necessary for other soil properties such as calcium carbonate distribution to resemble natural soils. Replacement of "topsoil" (material salvaged from natural soils before mining) results in mine soils more similar to natural soils. Because minesoils result from man-caused rather than natural processes, it is probable they will always remain different from natural soils. Although minesoils are different than natural soils, they are not necessarily inferior. Minesoils constructed with high quality material in stable slopes can be highly productive, perhaps surpassing the potential of natural soils in some cases. The unique properties of minesoils will need to be recognized and understood to properly manage mined areas.

Limited water is one of the most important factors governing plant growth in the arid West. Minesoils should have a high water-holding capacity, and high infiltration rate to maximize reclamation potential. Minesoils in this study had rapid infiltration rates, which means that precipitation should enter the soil rapidly so that little run-off occurs. Despite rapid infiltration rates, excessive run-off and erosion were common on poorly vegetated mine soils during intense storms. Rapid vegetation establishment and other

erosion control measures are critical in protecting minesoils during the first years after reclamation.

Patterns of water use differed in natural soils, old and new minesoils. Plant communities on natural soils (mid- and short-grass prairie) used soil water conservatively. Water use began slowly in April and May, reached a peak in June, and continued at a slow rate through the summer. At the end of the growing season, much of the plant available water still remained in the root zone. Plant communities on old minesoils (half-shrubs and annual grasses) used water rapidly from May through July, depleting nearly all the available water in the root zone. Because of the complete use of water each growing season, old minesoils have very little available water in a dry year compared to natural soils which have a reserve of water remaining from the previous growing season. Plant communities on new minesoils (introduced perennial grasses) use water rapidly in early spring, but very slowly in the summer. Total water use for the growing season is similar to that in natural soils.

At least three to four years are required before root systems in minesoils resemble those in natural soils in weight and distribution. Roots develop most rapidly near the soil surface, but more slowly below 50 cm. Roots penetrate as deeply as six feet in natural soils and minesoils. Using a radioactive tracer, it was found that the only active roots late in the growing season occur below 75 cm. Less than 10% of all roots occur below that depth.

Three to four years were required for microbiological activity to reach the levels common in natural soils. More microorganisms were found in natural soils than in minesoils at the 10 to 50 cm depth. This could have been due to the higher organic matter levels in natural soils at these depths. Microbiological activity varied seasonally and was probably influenced by soil temperature, nutrient availability, and by changes in the amount of readily decomposable organic matter.

This final report is from SEA-CR Project No. 684-15-4 entitled "Effects of Species Root Distribution on Soil Biota-Genesis-Hydrological Characteristics".

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ACKNOWLEDGMENTS

The authors wish to express their thanks to the many individuals and institutions who made this work possible. The Western Energy Co. is due thanks for approving the study on newly reclaimed areas, and for lending equipment and personnel support during various phases of the study. The USDA Soil Conservation Service (SCS) participated extensively in the study. The SCS field office in Forsyth, Montana as well as the Montana State office aided in site selection, soil description, and sample collection. Dr. W.D. Nettleton and others from the SCS Soil Survey Laboratory in Lincoln, Nebraska assisted in sample collection and provided laboratory analyses of soil samples.

Mr. John Wyatt carried out much of the field research related to water movement and P^{32} uptake in conjunction with graduate studies at Montana State University. Dr. Reid Howald, the radiological safety officer, provided assistance in the handling and licensing requirements for P^{32} and neutron probe use. Dr. John Amend of the Chemistry department designed the anti-coincidence Geiger-Muller detector used for measuring P^{32} uptake.

Anne Camper, Debra Hansen, and Peggy Schaplow of the Microbiology department performed parts of the field and laboratory work involved with measuring ATP activity. Dr. Frank Munshower and Mr. Dennis Neuman performed selected soil analyses including trace element chemistry. Many thanks are due numerous other staff members of the Reclamation Research Unit and Plant and Soil Science department for helpful suggestions and review comments.

John A. Asleson served as Project Director for the Montana Agricultural Experiment Station, and Eilif V. Miller coordinated the effort for the Science and Education Administration, Cooperative Research, USDA.

This report was approved by the Montana Agricultural Experiment Station for publication.

SECTION 1

INTRODUCTION

Strippable coal deposits underlay 2.6 million acres of land in the Northern Great Plains. If energy demands grow as expected, approximately 100,000 acres will be mined in this region by the year 2000. Loss of productivity from this land area would have a small impact on region-wide agricultural production (NGPRP, 1975), however, impacts on local economy and on long-term productivity would be more significant. This loss of productivity coupled with public environmental concern makes rehabilitation of mined land a key issue in energy resource development.

The coal extraction process drastically alters the physical and biological nature (ecosystem) of a mine area. Rehabilitation of mined land is impossible without an understanding of geologic, hydrologic, biologic and edaphic processes operating in unmined landscapes. In addition, the characteristics of mine spoil must be well understood. Rehabilitation procedures are also dependent on the intended post mining use of mined land. Dominant land uses in the Northern Great Plains include 1) pasture and rangeland (69%), 2) dryland agriculture (25%), 3) forest and woodland (4%), 4) urban (1%), and 5) irrigated cropland (1%) (NGPRP, 1975). The potential may exist, through mining, of creating land resources designed to satisfy local needs such as stock-water impoundments, irrigated agriculture, quality pastureland, or urban development. Before these goals can be achieved, however, more knowledge about pre- and post-mine landscapes are needed.

A typical unmined landscape in the Northern Great Plains consists of 20 to 150 feet of weakly cemented sandstone, siltstone, and shale in varying amounts overlying a thick coal seam; a moderately developed soil immediately below the land surface formed during a 10,000 year period; and a plant community which has developed in response to the climate, soil, and grazing history at that location. After mining, this same area will consist of a rolling topography offractured rock mixed from all segments of the overburden without vegetation or established stream channels. Material salvaged from soil horizons before mining is respread to speed soil development. The mined landscape has been permanently altered. Successful rehabilitation of this land depends on our ability to understand differences between mined and unmined land and to isolate problems associated with mined areas.

In response to the need to better understand mined land, and in particular, soils on mined land, a study was initiated at Montana State University to evaluate soil development on mine spoil. Soil water flow patterns, root growth and development, and soil physical, chemical and microbiological properties were investigated on minesoils 1 to 50 years in age, and on undisturbed soils. Differences between minesoils and undisturbed soils, and changes in minesoils through time were evaluated.

SECTION 2

CONCLUSIONS

Soil Genesis

1. Processes which have formed natural soils in the Colstrip area are also occurring in minesoils. Only a small part of the change that created natural soils has occurred in 50-year-old minesoils.

2. The genetic youth of minesoils does not severely limit reclamation potential. In some cases the potential of minesoils is higher than for natural soils.

3. Some soil properties change rapidly in minesoils and may reach equilibrium in 200 to 400 years. These include organic matter content, pH, and soil structure. Other properties such as $CaCO_3$ distribution may require as much as 10,000 years to resemble native soils. Because of their unique origin, minesoils will probably always remain different than undisturbed soils in some ways.

4. Minesoils have wider C/N ratios than natural soils, and a large fraction of the total carbon and nitrogen in minesoils is in the form of plant litter. Organic carbon content in these soils increases rapidly near the surface but very slowly below 10 cm.

5. The amount and distribution with depth of extractable Fe, Mn, Cu, Zn, Ni, Cd, and Pb was similar in old minesoils and natural soils. Differences in concentrations with depth were related to organic carbon content, pH, clay content, and other soil properties. The extractable trace element levels in new spoils were closely related to the characteristics and origin of the overburden fragments making up the soil parent material. Levels of most elements were higher on new minesoils but did not for the most part exceed potentially toxic levels (Montana Department of State Lands, 1977). Evidence of movement and changes in the oxidation of Mn and Fe was observed in thin sections of new minesoils.

6. Bulk density of minesoils was closely related to the machinery used in deposition of the spoils. Side-dumping haul trucks used in construction of old spoils; and bulldozers, and draglines resulted in uncompacted mine soils. Use of scrapers, however, often resulted in compacted zones with bulk density of 1.7 to 1.9 g/cm^3. Few compacted layers were found within 20 cm of the soil surface perhaps due to freezing and thawing or wetting and drying of soils.

7. Some orphan spoils (ungraded ridges left from mining during 1930-1940) were found to have extremely acid surface horizons. Coal fragments with abundant pyrite underlay these acid spots. Development of low pH under

the semiarid climate typical of Colstrip indicated that high precipitation is not a prerequisite for acid-production. It is a result instead of the balance of acid-producing (pyrite) and neutralizing ($CaCO_3$) materials in the overburden. Nearly all overburden material in the western states contains a surplus of neutralizing materials.

Water Relations

1. Infiltration rates were moderately rapid on both undisturbed soils and minesoils. Despite the high infiltration rates, erosion was still a major problem on new minesoils. Rapid establishment of vegetation and use of erosion control is critical even on minesoils with moderately rapid infiltration.

2. The percentage of water held in soils in early spring after recharge was determined largely by the water-holding capacity of the soil. The pattern of water use through the growing season was influenced by the plant community on each soil. Communities on new minesoils consisting primarily of introduced perennial grasses used water rapidly in early spring in the upper 50 cm. Shrub-dominated communities on old minesoils used nearly all available water in the top 200 cm. Native plant communities used water conservatively but water use continued through most of the growing season unlike introduced plants on new minesoils.

3. Introduced plants on minesoils had the highest water use efficiency of stored soil water, but summer precipitation was not used to a significant extent. Native plant communities utilized summer precipitation but not as efficiently as they used stored soil water.

4. The sparse vegetation on young minesoils did not use much of the water available in the soil. As a result, drainage below the root zone would be expected to be greater from newly planted minesoils than from minesoils with well-established vegetation. Drainage of water from new minesoils may affect the quantity and quality of acquifers developing in spoils.

5. The water use pattern in minesoils with 4-to 6-year-old reclaimed plant communities was remarkably similar to natural soils. Proper reclamation techniques on suitable soil materials were more effective in reestablishing plant communities functionally similar to native communities than 50 years of succession on less suitable soils.

6. The soil moisture regime of all soils was ustic (subhumid) bordering on aridic. Soils would qualify for aridic subgroups of Mollisols, Entisols, and Inceptisols. The soil temperature regime of all soils was mesic but bordered on frigid. New minesoils were cooler than natural soils while old minesoils were warmer.

Root Activity

1. Soil temperature and water potential affect root activity but genetic

differences in plants make some species better able to withstand extremes of the soil environment.

2. Nearly twice as many roots occur in old minesoils as in natural soils and new minesoils. The roots in old minesoils are larger in size and a larger fraction occurs below 25 cm than in other soils. These differences in root characteristics reflect the deep-rooted shrub-dominated plant community on old minesoils. Deep-rooted plants have the advantage of increased drought tolerance by having a larger available reservoir of water as a result of the deeper root zone. However, less water per unit weight of roots is obtained by deep-rooted plants. Therefore deep roots form at the expense of above ground productivity since a larger fraction of photosynthate must be utilized by the root system.

3. Many perennial grasses, forbs, and shrubs have roots at least as deep as 150 cm in old and new minesoils; and in natural soils.

4. Roots below 50 cm comprise only a small fraction of the total root biomass but are extremely important in providing water and nutrients to plants late in the growing season.

5. Introduced perennial grasses common on new minesoils have higher root activity early in the growing season but plants also senesce earlier than native vegetation. Few species are active on minesoils after June while some plants remain active on natural soils at least through late July.

6. Four to six years were required for root systems to develop on new minesoils that are similar in biomass and distribution to root systems of native plant communities. Roots develop more rapidly at shallow depths than at deeper depths.

7. Root activity differed in 1976 and 1977. Rainfall distribution was also different in these two years. Roots were active at deeper depths in 1976 which had a wet spring. It appears that the response of root systems to environmental factors is dynamic so that growth patterns can adjust to yearly climatic fluctuations.

Microbiological Activity

1. Microbial activity, as measured by ATP levels at three points in the growing season, was within normal limits for range soils in the vicinity. This indicates a satisfactory level of microbial activity had been attained in all minesoils sampled. However, the 1948-3 site appeared to be lower in microbial activity than any of the others.

2. Seasonal variation in the ATP concentration with depth is apparent from the similarity between August and October ATP profiles when compared to June samples. Nevertheless, maximum ATP was high at most sites at a shallow depth. One exception to this generalization was the 1975-11 site which was sampled only once but had a lower-than-average ATP, with especially low surface and near-surface values. Coupled with the abnormal ATP depth profile of the site, this may reflect the youth of this minesoil.

Of all the sites sampled, the 1975-11 site showed the least resemblance to a normally-developed soil in the ATP picture. The oldest sites, deposited from 1920 to 1930 and with revegetation by voluntary seeding, had fairly consistent ATP profiles regardless of the type of plant cover which had developed.

3. ATP measurements indicate that all minesoils progressed within several years to a condition where microbial activity was at a level normal for the climate and vegetation of the area. Only two sites, one prepared in 1975 and sampled in 1976, and the other the 1948-3 site, failed to show this pattern of development of microbial activity. Of all sites, the 1972-13 site which has received perhaps more intensive management than most reclaimed sites, was the highest in microbial activity as measured by ATP.

SECTION 3

RECOMMENDATIONS

General

1. Based on an in-depth study of soils on mined land and on natural landscapes, several recommendations can be made regarding suitable techniques for reconstructing minesoils. These suggestions will not apply to all parts of the Northern Great Plains because of the unique conditions encountered at each mine.

   Material and Deposition: Best available material in a mine area should be used in rebuilding minesoils. In the Colstrip area, the A, B, and part of the C horizons of natural soils are consistently superior in quality to much of the overburden. However, some of the sandy-loam and loam-textured overburden low in salts is as good as the C horizons. With the aid of detailed soil surveys, it is suggested that 50 to 150 cm of the best quality soils be salvaged before mining and respread on the recontoured spoil surface at an average depth of 75 cm. When possible, cover-soil should be respread immediately after collection to avoid the need for stockpiling which may degrade soil quality. The upper layers of minesoils should consist of A horizon material because it contains more organic matter, will develop soil structure more rapidly, and contains native seed and plant parts that will aid revegetation. Cover-soil should be underlain by sandy loam or loam spoils with low EC and few siltstone fragments. Large differences in texture between spoils and cover-soil must be avoided so water and roots can penetrate the cover-soil/spoil interface. Use of scrapers to deposit spoils should be avoided where possible to prevent stratifications and compaction in the upper 200 cm of minesoils. When scrapers must be used, deposited material should be chiseled to reduce compaction and promote mixing of contrasting layers.

   Landscape Design: Fine-sand-sized material, which is dominant in Colstrip soils and overburden is easily eroded by running water. Long slopes with more than 8-12% slope should be avoided, unless strict conservation measures are implemented. Geomorphic principles should be used to design a stable slope form suitable for unconsolidated spoil material. Stable drainages with a coarser-textured channel bed should be constructed in a drainage network complimentary to the slopes,vegetation and watersheds created on the mined area. Long, planar slopes typical of reduced highwalls are particularly susceptible to rill and gully development and must be avoided. Convex slopes are common on some spoils, but are less stable than the concave slopes which develop on similar materials in the natural landscapes.

Management: Proper management of mined land is a key to successful reclamation. Since 3 to 4 years are required for root systems to develop, careful management including fertilization and irrigation may be desirable initially. After this establishment period, the degree of management required will depend on the type of vegetative cover. Use of introduced species will require more careful management and more frequent inputs than native plant communities. Heavy fertilization of introduced species results in high productivity, but also causes high rates of water use. As a result, little plant-available water will remain in heavily fertilized minesoils at the end of an average growing season. This is unlike natural soils which have a small reserve of water at the end of an average year. Consequently, these minesoils will be more adversely affected by a dry year, resulting in more erratic vegetative productivity. Another consequence of heavy fertilization is rapid litter accumulation. Enough litter accumulates on 3- to 6-year-old minesoils to retard productivity despite nearly equal amounts of microorganisms in minesoils and natural soils. Controlled burning or grazing properly used, are two techniques that may be employed to prevent litter accumulation. Establishment of native plant communities of a diverse nature with only moderate initial fertilization will result in more stable ecosystems with fewer management needs. Many years may be required for this goal to be reached successionally, however. Minesoils will never be identical to natural soils. They will often have a lower potential than the best natural soils before mining but if properly constructed are likely to be superior to many natural soils. Minesoils can support viable land uses if quality soil materials are utilized, minesoils are properly constructed, slopes are geomorphically stable, and reclaimed areas are suitably managed.

2. The number of years required for mined land to be adequately restored depends on the final land use. When the final use is livestock grazing as in the Colstrip area, the time required is determined by the type of vegetative cover desired: introduced species or native. When introduced species are used, 3 to 4 years are required for root systems to develop and for perennial plants to become established. If periodic fertilization, controlled grazing, burning, and perhaps irrigation are acceptable as required management tools, then mined areas may be "restored" at Colstrip in as little as five years. If these management requirements are not acceptable, and a self-sustaining, diverse cover of native species is desired, then up to 20 years or more may be required. New techniques for establishing native species may shorten this time period. To speed nutrient cycling of nitrogen, phosphorus, and some other essential nutrients, techniques to rapidly increase organic matter content should be applied. These techniques include use of coversoil high in organic matter, incorporation of sludge or other organic wastes, or repeated cropping of vigorous annual grains which produce extensive root systems.

3. Development of a classification for minesoils would group minesoils

with similar management needs, properties, and limitations into defined units. In this way, research results on particular kinds of minesoils could be extended or adapted to minesoils in other areas. The current system used in the U.S. for classifying soils is the Seventh Approximation or Soil Taxonomy. This system classifies soils on the basis of diagnostic properties and diagnostic horizons. Diagnostic properties include soil temperature, soil water availability, soil mineralogy, and soil chemical or physical properties which are all measured in the field or easily obtained through laboratory tests. The presence of certain diagnostic horizons and properties are influenced by soil development processes. Problems occur when minesoils are classified using the Soil Taxonomy because man's influence on soil development is not currently recognized in the definition of diagnostic horizons. For example, soft rock fragments common in minesoils are not often observed in natural soils. As a result soft rock fragments must be grouped with lithic rock fragments, but their influence on soil response is very different. In natural soils, the presence of excess sodium is recognized when a natric horizon is present. However, minesoils with excess sodium do not have natric horizons because of their genetic youth, and therefore sodium in minesoils cannot be formally recognized. Fortunately, Soil Taxonomy was designed to allow changes so that new soils can be formally classified. One approach to classify minesoils would be to formulate new family criteria which recognize the unique properties of minesoils. With this approach, most but not all, minesoils would be Entisols. Minesoils in this study would be Typic Ustorthents. To formally classify minesoils at higher levels of Soil Taxonomy, new diagnostic horizons and properties will need to be defined which recognize man's influence as a soil-forming factor. At the present time, the best way to classify minesoils is to define them at the series and phase level. The soil series is the lowest level which is recognized in soil classification, and as such limits of soil properties can be narrowly defined. The soil phase is based on recognition of properties in the field which affect management but are not considered in soil classification. Soil phases are useful for mapping minesoils because of their flexibility.

Genesis

1. Reclamation methods such as application of "topsoil" create minesoils similar in some respect to undisturbed soils. These techniques simulate hundreds to thousands of years of soil development on raw spoils. No reclamation techniques produce minesoils identical to natural soils, however. Differences between mined and unmined landscapes need to be recognized to properly manage reclaimed land.

2. Controlled burning or grazing should be investigated as management techniques for preventing litter accumulation which immobilizes nitrogen and organic carbon in the developing soil system. These techniques will accelerate the breakdown of litter, narrowing the C/N ratio, and may ultimately enrich the organic matter content of deep soil layers by promoting greater root growth.

3. The man-influenced origin of minesoils has resulted in several unique properties not commonly observed in undisturbed soils. Minesoils in Colstrip have a high volume of soft weatherable rock fragments that supply water to plants but prevent root penetration. Fragments break down in the upper 20 cm of mine soils in 50 years. These fragments act in part like rock and in part like soil. Soil texture is continuously modified by their breakdown over a long period of time, especially where shale fragments occur in sandy soil. The role of soft rock fragments in minesoils is not yet understood. Abrupt changes in texture are a common occurrence in minesoils. These stratifications or pockets of texturally contrasting material could strongly influence water, and solute movement; and root growth. Research on water movement in stratified media should be applied to minesoils.

4. Federal strip-mine reclamation regulations (OSM, 1977) requires that the A horizon of pre-existing soils must be salvaged for "topsoiling". Selected overburden can be substituted for the A horizon if it can be shown to be of equal or better quality. Overburden used as "topsoil" did not have as favorable soil properties for plant growth as did A horizon material in this study. Overburden was lower in organic matter, water-holding capacity, and nutrient levels. More than 50 years would be required for some overburden to become as suitable as salvaged A horizons.

5. Federal regulations (OSM, 1977) also require that the B and part of the C horizon of soils be salvaged and re-applied if necessary to obtain soil productivity in the root zone compatible with the final land use. In this study, overburden should in many cases be as productive or more productive than the C horizon of pre-existing soils. Overburden should, therefore, be a suitable medium for use in the base of the root zone (from 2 to 6 feet) in the Colstrip area. If applied topsoil and the underlying spoil differ by more than two classes in texture, however; the topsoil/spoil interface may restrict rooting. Abrupt textural changes should be avoided in the upper 4 feet of reclaimed soils to create an adequately deep root zone.

6. Topsoiled mine soils appear to be more erodible than similar natural soils before mining. This could be due to loss of soil structure, plant cover, and the disruption of soil pores in the reclamation process. To prevent excessive erosion; lower slopes, shorter slope lengths, and rapid vegetation establishment should be emphasized. Reduced highwalls present a major erosion hazard because of moderately steep, long slopes. Preservation of intact highwalls (Murray, 1978) may mitigate erosion problems in these situations.

Water Relations

1. Reclamation techniques should be aimed at building minesoils with physical properties in the root zone similar to natural soils. Compacted layers and abrupt changes in texture which may limit root penetration for plant communities to develop which are similar to those before mining.

2. Moderately rapid infiltration rates are not sufficient to prevent erosion on minesoils. Rapid establishment of a plant cover and reduced slope and slope length are necessary to prevent excessive erosion of mined land. Sandy soil textures favor rapid infiltration but also result in lower water-holding capacity. Intermediate textures such as loam, sandy clay loam, and sandy loam may represent the best combination of favorable water-holding capacity with adequate infiltration rates.

3. Water is used by plant communities on new minesoils dominated by introduced perennial grasses and shrubs mostly during early spring through early summer. More efficient use of water during the summer could result if more warm-season species are established in reclaimed plant communities.

Root Activity

1. Common range plants in the Colstrip area have roots to nearly 2 meters on both minesoils and undisturbed soils. Therefore reclamation techniques should be aimed at providing a 2 meter root zone free of compacted layers limiting to root penetration and chemically suitable for root growth.

2. Root activity varies from year to year and is influenced by extremes in the soil environment such as low temperature and low soil water potential (dry). It appears that three to four years are required for the root system of plant communities on reclaimed land to resemble root biomass and distribution prior to mining. Supplemental irrigation during the developmental stages of plant communities may increase the chances for successful vegetation establishment during adverse years.

SECTION 4

LITERATURE REVIEW

Soil Genesis

A soil consists of a vertical sequence of layers or horizons, each with a unique combination of properties such as: pH, organic matter content, texture, and mineralogy. Jenny (1941) stated that the arrangement, kinds, and properties of horizons in soils are the result of five soil-forming factors. These factors are climate, organisms, parent material, relief, and time. Jenny further proposed that each factor had an independent effect on soils. In the past 35 years, numerous studies on single factors of soil formation have been conducted (Birkeland, 1974).

Other workers have proposed different approaches to the study of soil development. The independent influence of a single soil-forming factor is often difficult to isolate in nature. Hole and Nielsen (1970) suggest that the "factors" combine and interact to produce general "processes" of soil formation (Simonson, 1959). These processes acting through time on a newly-forming soil produce distinct properties. For example, the process of "melanization" produces a thick, dark, A horizon high in organic matter content. Likewise, the processes of eluviation and illuviation tend to either remove soluble salts and $CaCO_3$ from the profile or produce distinct layers of these materials deep in the profile.

Early Stages of Soil Genesis - Classic Studies: Initial stages of soil development have been studied on dune deposits (Salisbury, 1925; Jenny and others, 1969; Olsen, 1958), Mt. Shasta mud flows (Dickson and Crocker, 1953a, 1953b, 1954,) and glacial till (Crocker and Major, 1955). All workers found that vegetation strongly influences initial soil development. Ulrich (1956) and Yaalon (1975) emphasize the importance of parent material in determining the properties and genesis of young soils.

Dickson and Crocker (1953a, 1953b, 1954) studied soil development and vegetation succession on Mt. Shasta mudflows from 27 to 1200 years old. Organic carbon, total nitrogen, pH, and bulk density changed rapidly during initial soil development and were strongly influenced by vegetation. Total organic carbon and nitrogen in the soil and litter increased to a maximum in 200 years. A gradual flux of total C and N progressed from litter to soil for 500 years. Bulk density, pH, C, and N approached "steady state" (Birkeland, 1974) levels in the soil in 200 to 500 years. A similar pattern of soil development was found in recent glacial till in Alaska (Crocker and Major, 1955), and in northern California sand dunes (Crocker, 1967). Total nitrogen reached a maximum in 100-year-old glacial till then decreased, instead of approaching a "steady state" value as in the other chronosequences.

Olsen (1958) studied soil development on a sequence of Lake Michigan sand dunes 0-12,000 years old. Organic carbon and nitrogen in the upper 10 cm rose quickly in the first 300 years, and more slowly until steady state was approached in 1,000 years. $CaCO_3$ content was initially 1.5 to 2.0 percent in the sand but was nearly removed from the upper 10 cm of the soil in 600 years. The average depth of leaching of $CaCO_3$ was 2 m after 6,000 years. Silt and clay content rose from near zero initially to an equilibrium level in 1,000 years. Silt and clay content again increased in 8,000- to 12,000-year-old soils probably as a result of loess deposition during the Pleistocene.

Parsons and others (1962) investigated soils on Indian mounds of known age in Iowa. He compared relative profile development of 1,000 to 2,000-year-old mound soils to undisturbed soils on 14,000 year old loess. Horizonation developed most rapidly in the first 1,000 years of soil development. A1 horizons reached maximum expression in 1,000 years, while 2,500 years were required for pronounced soil structure to form and clay translocation to become evident. Bilzi and Ciolkosz (1977) found cambic horizons in 200-year-old alluvium and 40-year-old minesoils (Ciolkosz and others, 1977) in Pennsylvania. They reported that 2,000 years were required for argillic horizon formation in Oregon while more than 5,000 years were required in New Mexico.

The general pattern of soil development is for levels of properties to change quickly during initial stages then change less rapidly as equilibrium is approached. The amount of time required to reach equilibrium is different for each property. Organic matter, pH, and total nitrogen can change quickly in soils (100-500 years). Carbonate movement requires more time (>1,000 years), while clay movement may require 2,000 to 10,000.

Minesoil Genesis: Smith and others (1971) studied soil genesis in iron-mine spoils in West Virginia. Spoils had deeper rooting, higher cation exchange capacity, and higher exchangeable nutrients than natural soils. Natural soils had lower bulk density, higher porosity, stronger soil structure, and higher nitrogen and organic carbon contents. Water regimes in the top two feet were similar in spoils but natural soils had higher infiltration rates. The authors concluded that minesoils were superior to natural soils in some respects while inferior in others. The minesoils were expected to support woodland and pasture as productive as on unmined soils.

Wali and Freeman (1973) studied species composition and soil characteristics of North Dakota mine spoils compared to adjacent undisturbed areas. Spoils had higher pH; electrical conductivity; exchangeable magnesium, and sodium; total phosphorus, and sulfur; and silt, and clay content. Unmined sites had more organic carbon; exchangeable potassium; species diversity, abundance, and density. Some mined sites did not support "desirable" plant species 53 years after mining.

Caspall (1975) found that organic matter content increases rapidly with time in the top few cm of Illinois minesoils. Organic matter increases more slowly below about 5 cm. After only 14 years, organic matter in the upper 12 cm of minesoils was about 60 percentof equilibrium levels. Depths of carbonate leaching increased from 4 cm in 14-year-old minesoils to 15 cm in 30 years.

Down (1975) reported on soil development in colliery waste tips in England. Accelerated erosion occurred in all spoils (32°-36° slope). However, sheet and gully erosion was less rapid on spoils more than 20 years old. Particle-size decreased with increasing age due to weathering of shale fragments, and surface coal content also decreased with age from 54 percent initially to 2.5% after 178 years. An ameliorative effect of fine coal fragments on soil structure and nitrogen status was noted.

Anderson (1977) investigated changes in glacial till mine spoil in Saskatchewan ranging from 28 to 40 years in age. Soluble salts had been leached below 50 cm, and large amounts of carbon and nitrogen had accumulated. Humus in 28-year-old minesoils was very similar to that found in natural soils.

Soil Development in the Northern Great Plains: McKeague and St. Arnaud (1969) state that water movement is the most important phenomenon in soils leading to profile differentiation. Components of soil vary in their mobility with moving water. Mogen and others (1959) found successive accumulations of carbonate, gypsum, and soluble salts with increasing depth as a result of differential mobility in North Dakota soils. Redmond and Omodt (1967) studied till-derived chernozem soils in eastern North Dakota. Dominant soil development processes included organic matter accumulation; structure formation; leaching of soluble salts and carbonates; color changes; and formation of finer-textured B horizons due to clay eluviation and *in situ* clay formation. Curry (1975) suggested that the development observed in Northern Great Plains soils are a remnant of a wetter climate several thousand years ago. The results of Anderson (1977) and this study (Schafer and Nielsen, 1978; Schafer, and others, 1977) indicate that many of the soil development processes outlined above are active in 50-year-old minesoils. Minesoils should become more like natural soils with increasing age since the same processes which have occurred in the development of natural soils are active in minesoils.

Soil Water Relations in Spoils

The availability of water for plant growth is one of the primary limiting factors in reclamation of western mined land (NAS, 1974). The amount of water available for plants depends on precipitation, infiltration, run-off, and water movement into or out of the base of the root zone. Several workers have studied these and other factors influencing water movement in minesoils.

Infiltration: low infiltration rates on minesoils cause increased runoff which can reduce plant available water, remove applied topsoil, and create sedimentation problems. Erosion and reduced infiltration are therefore major problems in arid mine land reclamation.

Gilley and others (1976b, 1977) measured run-off and erosion on native range, and topsoiled, and non-topsoiled spoils in North Dakota using a large rainfall simulator. Two storms of one hour duration and 2.5 inch/hour intensity were simulated. Soil loss on native range was 200 kg/ha; only 12% of the applied water ran off the plots. Water from both events moved deeply into the profile (>18 inches).

Soil loss on raw spoils was 15,000 kg/ha and 21,000 kg/ha on cultivated and uncultivated erosion plots. Run-off consisted of 66 to 74% of the applied water. Water did not penetrate significantly into uncultivated spoils and increased only in the upper 6 inches of cultivated plots. Cultivation of the topsoil/spoil interface did not increase percolation into the spoils. As slope was decreased from 17 to 6%, soil loss was reduced by about 30%. Differences in spoil texture had little influence on soil loss.

Erosion was greatest on topsoiled spoils at 74,000 kg/ha. As topsoil thickness of the treatments was increased from 25 to 61 cm, run-off decreased but erosion increased. Water content of the topsoil zone increased after the rainfall events, but no water entered the underlying spoils. Application of straw mulch decreased erosion on topsoiled and non-topsoiled plots by 93 and 84% respectively.

Erosion was less on spoils without topsoil because a surface crust formed on the clayey sodic materials which slowed erosion. Topsoil materials on spoils were more erodible than similar undisturbed soil in part due to a loss of soil structure during the handling process (Gee and others, 1976). Water content of topsoil increased rapidly during the rainfall events. Gilley and others (1976a) found that eroded material from uncultivated spoils had a particle size distribution similar to the surface spoil. Sediment from the cultivated plots had less sand and more clay than the spoil.

Miyamoto and others (1977) reported that some spoils in New Mexico were non-wettable and as a result had slow infiltration rates. High-grade coal was identified as the source of the hydrophobic substance. Addition of ethyl alcohol significantly increased infiltration into coaly spoil by decreasing the contact angle thus increasing capillary adsorption. Infiltration into sodic, non-coaly spoils was not affected by addition of ethyl alcohol, but was increased by adding $CaCl_2$ to the irrigation water. Miyamoto (1978) tested several wetting agents to evaluate the feasibility of increasing infiltration on coaly spoils. Only anionic-type compounds significantly increased spoil wettability. The effectiveness of anionic sulfonate may have been due to the anion adsorption capacity of low pH coal.

Arnold and Dollhopf (1977) found that minesoils in southeastern Montana had slower 30 minute infiltration rates than undisturbed soils. The presence of vegetation or application of topsoil significantly increased infiltration into spoils, however. Dollhopt and others (1977) found a similar result on spoils at Colstrip and Savage, Montana; and Beulah, North Dakota. Infiltration on selected surface soil treatments decreased in the order topsoil/chiseled > non-topsoil/chiseled > topsoil/dozer basin. The dozer basin treatment removed topsoil from the basin area, and in addition compacted the underlying spoil. Therefore, infiltration was highly influenced by the surface material and decreased from topsoil to spoil to compacted spoil.

Wyatt (1978), working with data from this study, found that infiltration rates on native range, old spoils, and new spoils were not significantly different. Spoils and soils were predominantly sandy loam in texture and were non-sodic. Application of topsoil derives its maximum benefit when the spoils are clayey, sodic, or high in coal content. Although topsoil often increases infiltration, and can store more water than spoils; it is very erodible with a small amount of run-off and therefore must be protected during the early stages of reclamation.

Water Use and Movement: Once water penetrates the soil surface by infiltration it can move downward under the influence of gravity, upward or downward in response to matric potential gradients, or be used by roots. The interaction of these processes and others causes water to move differently in different soils. Water movement and plant use of water has not been extensively studied in minesoils .

Dollhopf and others (1977) studied the water balance at three Northern Great Plains strip mines under five different erosion control treatments. They found that water recharge was greatest on topsoiled plots. Dozer basins were the most effective surface manipulation for increasing recharge. Water content in the upper 50 cm was at a maximum in February. Upward vapor movement of water to the frozen soil zone was postulated to occur as a result of temperature gradients (Ferguson and others, 1964; Willis and others, 1964). Water was used most rapidly from June to August. Soils remained dry through most of the fall. Evapotranspiration averaged 75, 57, and 47 cm per year at Savage, Montana; Colstrip, Montana; and Beulah, North Dakota. A net upward movement of water from below the root zone (250 cm) occurred at most sites. It was not known whether upward movement of water would cause salt accumulation.

Curtis (1973) measured the water content and density of former ridge and valley locations in a regraded Kentucky stripmine. Former spoil ridges were more compacted and contained less water than valleys. Compaction may have been due to the compressive weight of the spoil material or vehicle traffic during regrading. Surface density on all spoils decreased during the first winter after deposition probably as a result of frost action.

Arnold (1977) found that the hydraulic conductivity (K) of native range soils (4.9 cm/day) was greater than all spoils studied (1.3 cm/day). Topsoiled spoils had higher K values in the topsoil zone than in the underlying soil. Drainage below the root zone of fallow native range and spoils was calculated. Assuming the soil was recharged to field capacity in the spring, 2.5 to 4.0 cm would drain in one year from spoils and native range respectively.

Gilley and others (1976a) found that topsoiled spoils had higher infiltration than raw spoils. However, water did not penetrate the topsoil-spoil interface. Cultivation of the interface to increase contact did not influence percolation into the spoils. Restricted percolation of water below the topsoil zone was also observed by Dollhopf and others (1977). It was suggested that physical and chemical treatments to decrease compaction and minimize clay dispersion would be necessary to increase deep percolation. Henning and Afflect (1977) in Iowa found that deep tillage of compacted spoil sublayers increased infiltration, deep water movement, and initial corn growth.

Grassland Root Systems

The underground portions of plants comprise one of the most important components of an ecosystem as well as the most difficult to study (Troughton, 1957). Several methods have been used to study root weight and length; and the seasonal dynamics of live, dead; functional, and senescent roots.

Knowledge of the maximum rooting depth of range plants is important in planning mine reclamation. Minesoils should be created which provide a root zone sufficiently deep to support the reclaimed plant community. The root zone should be free of physical barriers to growth and chemically harmful zones.

Methods: One of the most straightforward methods of characterizing roots is to excavate a trench and sketch the root distribution observed in the profile. A monolith can be extracted from the trench and washed free of soil to further isolate the root system. Weaver and associates used these methods to produce volumes of information on the distribution and depth of roots of numerous plants in North American prairie (Weaver, 1919; 1920; 1958; Weaver and Darland, 1949; Albertson, 1937). These methods are time consuming and provide only qualitative information, however.

The framed monolith method is similar to the previous one in that a large soil monolith is collected in the field and washed free of soil. After soil removal, roots are subsampled by depth increment for obtaining root weights. The framed monolith method is probably the most accurate but also the most time consuming method of studying roots (Bohm and others, 1976). Soil cores are often used instead of intact monoliths in many root studies. Individual cores can be subsampled by depth and washed free of soil. Many cores are necessary to measure root biomass because of the small sample size (Schurman and Goedewaagen 1965). Special man-operated (Brown and Thilenius, 1977) and hydraulic coring devices (Bartos and Sims, 1974) have been used to speed sample collection. Root separation by hand is very time consuming so that machines have also been developed to speed this process (Brown and Thilenius, 1976). Repeated measurements of root weight have been used to study the seasonal changes in root biomass (Bartos and Sims, 1974; Dahlman and Kucera, 1965; Lauenroth and others, 1975; Schuster, 1964).

Tracer techniques have also been widely used for studying root systems. These methods are well-suited for studying the changes in the seasonal dynamics and function of roots; but are not widely used for estimating root weight. The radioisotope P^{32} is most commonly used for studying roots. Radiophosphorus can be injected at any selected soil depth, and if roots are growing in that layer, P^{32} will be transported to the plant top. Thus, root distribution can be inferred from the presence or absence of P^{32} in harvested plant tops (Boggie and others, 1958; Burton and others, 1954; Cooper and

Ferguson, 1964; Hammes and Bartz, 1963; McClure and Harvey, 1962). Differences in root activity with depth have also been investigated by observing differences in the amount of P^{32} taken up at different depths (Fox and Lipps, 1960; Lipps and others, 1957). Root distribution has been investigated by injecting P^{32} directly into the plant and then measuring the radioactivity of soil cores after the P^{32} is distributed evenly in the plant (Halstead and Rennie, 1965; Rennie and Halstead, 1965). Finally, P^{32} has been used to study translocation of materials within the plant (Racz and others, 1964; 1965; Sosebee and Wiebe, 1973).

Radiocarbon, C^{14}, has been widely used recently to study the functional dynamics and productivity of root systems (Caldwell and Camp, 1974; Singh and Coleman, 1973 and 1974). The plant top is exposed to labeled CO_2 under an airtight tent. After a selected period of time, roots from the treated plant are core-sampled and measured for C^{14} enrichment. Other stable isotopes such as lithium, strontium, and rubidium have also been used to study root growth (Fox and Lipps, 1964).

Root Biomass: Several measurements of root biomass have been reported that are applicable to the Colstrip region. Lauenroth and others (1975) found that root biomass in the upper 10 cm of soils near Colstrip generally increased from May through July then decreased during the fall. Values for root biomass averaged 500 g/m^2 in the upper 10 cm of some communities dominated by *Stipa comata*.

Singh and Coleman (1973) measured root biomass on Colorado short-grass prairie dominated by Blue grama *(Bouteloua gracilis)* and Buffalograss *(Buchloe dactyloides)*. Root biomass in theupper 60 cm of the soil was 1894 g/m^2 of which 66% of the roots were functional as determined by C^{14} assimilation. Bartos and Sims (1974) studied similar plant communities under variable grazing pressure. Root weight in the upper 80 cm reached a maximum in early summer and again in early fall. The average biomass was 1275 g/m^2 in 1969 and 1702 g/m^2 in 1970. Root biomass in the upper 10 cm varied most during this period. They reported that most roots occured in the upper 10 cm probably in response to the shallow penetration of precipitation in that region.

Dahlman and Kucera measured root biomass during different seasons in Missouri tall-grass prairie. Biomass varied from a minimum of 1449 g/m^2 in April to a maximum in October of 1901 g/m^2. Peak root biomass occurred in July for the 0-25 cm layer but was delayed in lower soil layers. Approximately 25% of the root system turned over each year, however, turnover rates were lower at lower soil depths.

Caldwell and Camp (1974) measured root biomass in two cool-desert communities, one dominated by *Ceratoides lanata* and the other by *Atriplex confertifolia*. Biomass in the 0-75 cm soil depth was 1541 and 1823 g/m^2 for the two communities respectively. Below-ground biomass was 7 to 11 times that of aboveground.

Seasonal dynamics: Many workers have studied changes in root systems through the growing season. Root weight; the proportion of live and dead, or functional and senescent roots have all been investigated in this manner. Models of root biomass dynamics have been developed based on the partitioning of C^{14} in the plant during different times of the year.

Root biomass in grassland ecosystems is at a minimum in early spring before root growth initiates (Dahlman and Kucera, 1974. Biomass increases rapidly and reaches a peak usually in mid-summer. A gradual decline in late summer is sometimes followed by a secondary increase in the fall (Bartos and Sims, 1974). From 12 to 25% of the root system is renewed each year in both Missouri prairie and Utah desert communities. This agrees with the findings of Weaver and Zink (1946) who found that root survival over a three year period was 81, 45, 14 and 10% for *Andropogon furcatus*, *Bouteloua gracilis*, *B. curtipendula*, and *Stipa spartea* respectively.

Singh and Coleman (1974) measured both root biomass and the percent of functional roots with depth. The proportion of functional roots decreased from around 70% in the upper 10 cm to 30% at 60 cm. This probably resulted from slower decomposition at depth. The specific activity (μCi/g roots) of roots from each depth was used to isolate zones of potential growth or storage of assimilate. Growth below 40 cm was most rapid early in the growing season. It was postulated that growth of deep roots was important for utilization of soil water. Specific activity of roots from 10 to 20 cm increased through the growing season. It is likely that photosynthate was being stored in these roots for use as energy reserves during the following year. Roots at this depth were observed to begin growth early in the growing season before any leaves had formed aboveground, which indicates the utilization of stored carbohydrates.

Boggie and others (1958) and Burton and others (1954) found that roots in the upper 10 cm of the soil transport over ten times more P^{32} to plant tops than do roots at deeper soil depths. Increased root abundance, phosphorus availability, or soil temperature or moisture could account for this difference. Burton (1954) found that differences in P^{32} uptake from deep soil zones correlated with root biomass distribution and drought tolerance in several southern U.S. grasses.

Fox and Lipps (1960, 1964) studied P^{32} uptake by alflafa in subirrigated fields in Nebraska. They found three distinct zones of P^{32} uptake in the soil including 1) an intermittently moist zone near the surface, 0-1.2 feet; 2) a dry, chemically inferior zone from 1.2 to 7 feet; 3) and a wet zone above the water table from 7 to 12 feet. Early in the growing season, 88% of the P^{32} accumulated from all depths came from the surface layer. Only 5% of the P^{32} was taken from the surface late in the growing season, however, when water was limiting. During this period 62% of the P^{32} was taken up from below seven feet even though only 3% of the root weight occurred below that depth.

Bartos and Jameson (1974) found that root biomass in short-grass prairie was highest in early summer and again in early fall with a minimum occurring in mid-summer. They explained this phenomenon by formulating a model which recognized a decomposition process causing weight loss and a new growth process resulting in biomass increase. Maximum decomposition was postulated to occur slightly before maximum growth accounting for the minimum root biomass during mid-summer, a period of active growth. When decomposition was set at 40% of the total biomass, which is a maximum value from the literature, the combination of the growth and decay processes did not adequately fit the observed data. They suggested that other processes may be involved in the mid-season biomass minimum, or that more decomposition occurs than is commonly recognized. Assuming these large decomposition rates are valid, more than 80% of total plant photosynthate would be used in new root growth each year.

Ares and Singh (1974) investigated the dynamics of root biomass under short-grass prairie dominated by *Bouteloua gracilis* by modeling carbon flow between various sources and sinks. Carbon was depleted from root crowns early in the growing season before the appearance of new leaves for early growth of juvenile roots. The carbon in root crowns was replenished later in the growing season. Carbon reached a maximum in juvenile, non-suberized, and suberized roots at progressively later times in the growing season. Carbon in dead roots peaked in the fall and continued to increase gradually until the following spring. Carbon in dead roots was depleted by decomposition rapidly each spring when soil temperature rose high enough to stimulate microbial activity. Carbon lost by root respiration had a similar peak in late spring and summer. Models such as this suggest the complexity of the interactions of root growth, decay, and environmental conditions such as soil water and temperature.

Microbiological Activity

Microbial activity is an essential part of the soil-forming process, because such activity is directly related to soil aggregate stability. Initially, a reclaimed strip mine soil (termed "spoils") would have no horizon development, and one would expect to find relatively low levels of microbial activity. As spoils progress to a state supporting plant life, the level of microbial activity can be expected to change. Hence, the monitoring of microbial activity near the minesoil surface may be one index of soil genesis itself.

Recently there has been much interest concerning the measurement of the high energy, energy transfer molecule adenosine triphosphate (ATP) as a means of measuring microbial activity. ATP is found in all living systems. Within a bacterial cell ATP concentration will remain relatively constant throughout the organisms growth curve (Atkinson, 1971), and under most conditions is destroyed immediately upon the death of the cell (Holm-Hanson and Booth, 1966). The measurement of ATP is based on the observations of McElroy and Strehler (1949) who described the light emission resulting from the mixing of ATP with heat stable (luciferin) and heat labile (luciferase) extracts from the luminous crustacean *Cypridina hilgendorfi*. Since one photon of light was emitted for every molecule of ATP, quantitative measurements were possible.

The determination of microbial activity in soils utilizing ATP measurements has been an area of active research. MacLeod, and others (1967) measured ATP concnetrations in twenty-five terrestrial soil samples, finding values ranging from 1.2×10^{-7} to 8.0×10^{-9} g ATP/g soil. These concentrations are within the range of the findings of Doxtader (1969) who detected as little as 6.0 x 10^{-10} g ATP/g soil. Similarly Greaves and others (1973), while investigating microbial populations in basin peat, found ATP concentrations to range from 6.3 x 10^{-8} to 9.4 x 10^{-7} g ATP/g soil. These findings indicated that ATP was a reliable parameter in its own right, and was therefore used in this study as the primary means of assessing microbial activity in minesoils.

SECTION 5

STUDY AREA

Colstrip was chosen as a study area because of its relatively uninterrupted history of mining since 1924. Nearly level mine spoils ranging in age from 1 to 50 years provided an ideal setting for the study.

Location

Colstrip is located in the northern portion of the Powder River basin in the Northern Great Plains physiographic province. It lies in southeastern Montana along the East Fork of Armells Creek which is a tributary of the Yellowstone River 50 km (30 miles) to the north (Fig. 1). The study area was unglaciated during Pleistocene time, but late Tertiary uplift of the region caused downcutting of rivers and rejuvenation of much of the landscape (Fig. 2).

Geology

Geologic history of the region since Pre-Cambrian time includes periods of deposition, erosion, and deformation. During Paleozoic and Mesozoic time a sequence of carbonates, sandstones, and shales was deposited (Fig. 3). The area was a tectonically stable epicontinental sea during these periods.

Several hundred meters of clastic rocks were deposited during Cretaceous time as a result of repeated transgressions and regressions of the sea. Broad regional uplift after deposition of the Bearpaw Shale is believed to have caused permanent withdrawal of marine water from the region (Gill and Cobbin, 1973). The late Cretaceous Hell Creek Formation which overlies the Bearpaw Shale is of fluvial and lacustrine origin (Lewis and Roberts, 1977).

Subsidence of the present Powder River Basin began during deposition of the Hell Creek Formation in late Cretaceous time (Curry, 1971). Subsidence corresponded to the beginning of the Laramide orogeny during which the Black Hills and Big Horn Mountains bordering the basin were uplifted. The lack of coarse clastics and conglomerates in late Cretaceous and Paleocene deposits suggests that major uplift of the Big Horn Mountains and Black Hills didn't occur until Eocene time. At the close of the Cretaceous, large amounts of material were being deposited in swampy flood plains of the newly-formed Powder River Basin (Lewis and Roberts, 1977), setting the stage for deposition of the Paleocene Fort Union Formation.

The Fort Union Formation is divided into the Tullock, Lebo, and Tongue River Members in southeastern Montana. Other workers treat these as formations in the Fort Union Group (Curry, 1971; Jacobs, 1973). The basal Tullock

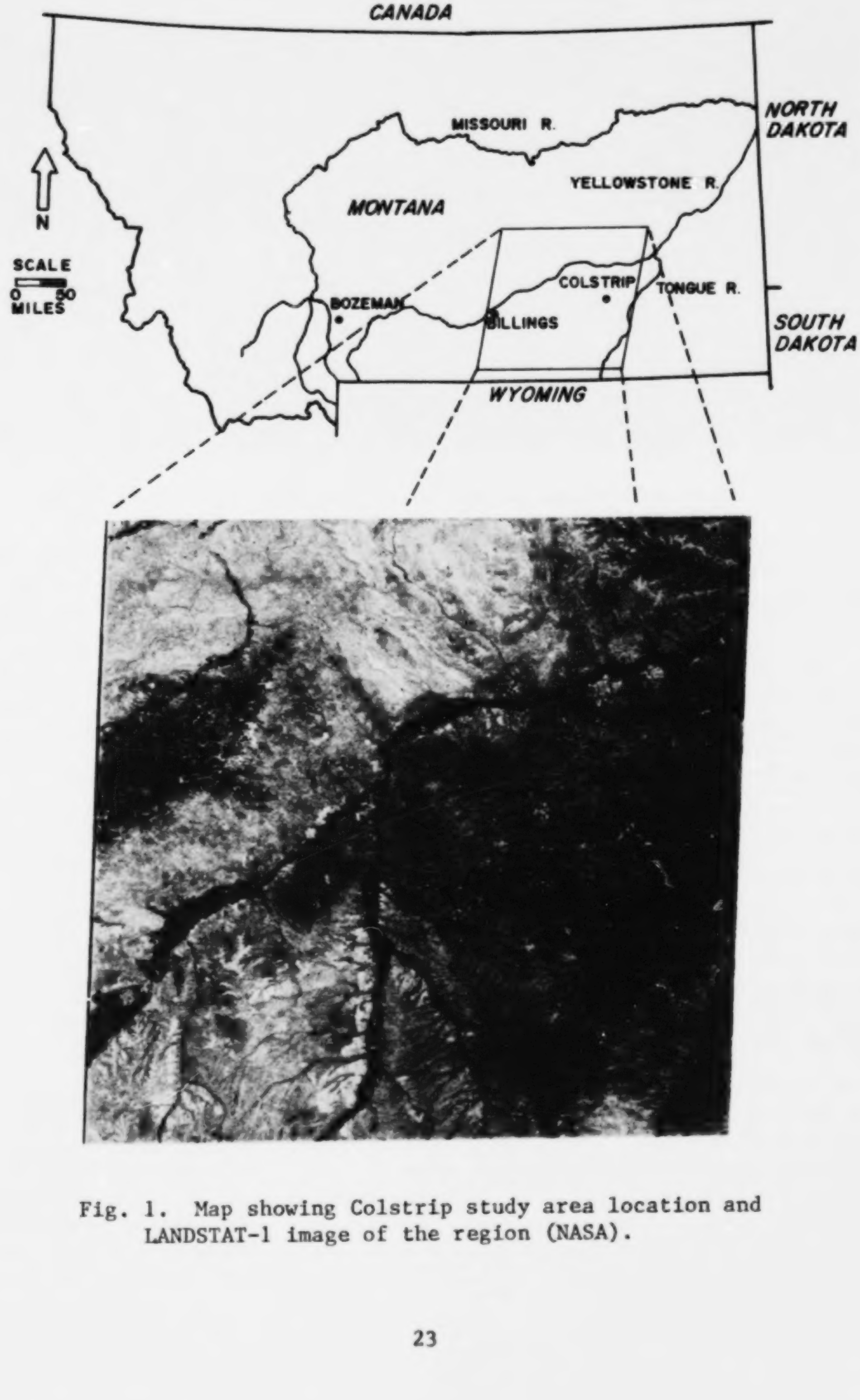

CANADA
MISSOURI R.
NORTH DAKOTA
YELLOWSTONE R.
MONTANA
N
SCALE
0 50
MILES
COLSTRIP
TONGUE R.
BOZEMAN
BILLINGS
SOUTH DAKOTA
WYOMING

Fig. 1. Map showing Colstrip study area location and LANDSTAT-1 image of the region (NASA).

Fig. 2. Typical landscape in the Colstrip area.

Member of the Fort Union contains an abundance of sandstone and thin coal deposits. Sediments were deposited in a fluvial environment of low topographic relief with abundant temporary ponds and marshes (Lewis and Roberts, 1977). Intervals of erosion and nondeposition are common in this member as inferred from abrupt truncation of cross-bedding, and channel sands cutting across shale and coal beds. The Lebo Member consists of shale and mudstones deposited in a similar environment. Locally, the Lebo Shale was derived from lacustrine processes. Deposition of the Lebo Shale corresponds to a period of rapid subsidence of the Powder River Basin. Uplands which currently border the basin were not yet a significant sediment source (Curry, 1971).

The Tongue River member of the Fort Union Formation contains some of the most extensive reserves of coal in the world. In western North Dakota, Tongue River sandstones are mostly fine to very fine grained subangular subgraywacke commonly showing a characteristic "salt and pepper" speckling (Hickey, 1977). The dominant cement is calcite. The degree of induration depends on the amount of cement, but most rocks are weakly cemented. Limestone sand grains are common indicating exposure of carbonate rocks in the sediment source area (Jacob, 1973). Claystones in the Tongue River Member contained a mixture of illite and kaolinite with lesser amounts of smectite.

In western North Dakota, four primary lithologic associations are common in the Fort Union Formation (Jacob, 1973). 1) Gray clay and silt units from 1 to 30 feet thick with disturbed stratification, and thin coal stringers are common. These represent floodplain deposits in a low relief fluvial environment. 2) Thick coal seams often overlie the gray silt and clay units and represent a swampy floodplain zone of deposition. The tabular blanket-like geometry of these seams may indicate a lower delta plain origin for the Fort Union in western North Dakota. 3) Yellow silt and sand deposits up to 50

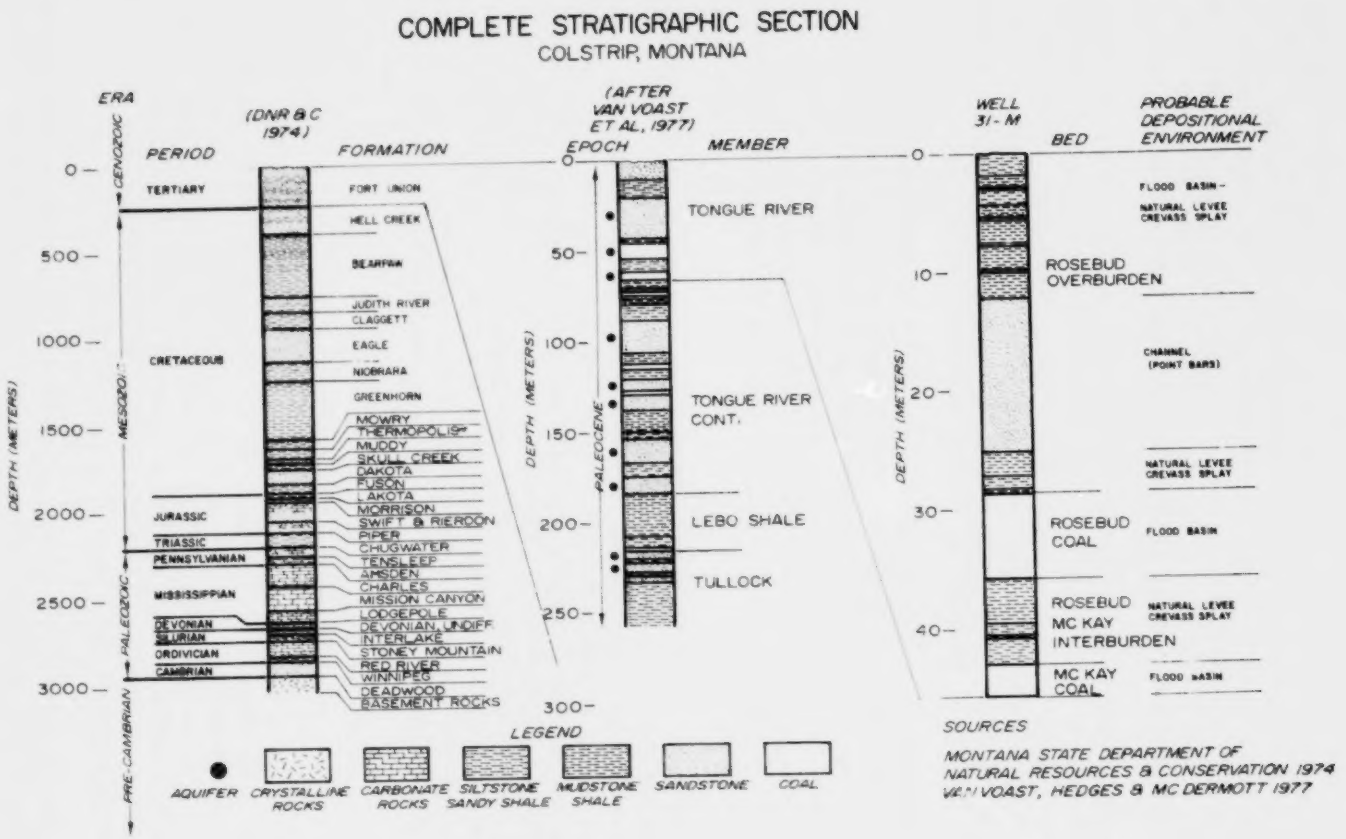

COMPLETE STRATIGRAPHIC SECTION
COLSTRIP, MONTANA
ERA
PERIOD
(DNR & C 1974)
FORMATION
DEPTH (METERS)
0
500
1000
1500
2000
2500
3000
CENOZOIC
MESOZOIC
PALEOZOIC
PRE-CAMBRIAN
TERTIARY
CRETACEOUS
JURASSIC
TRIASSIC
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
FORT UNION
HELL CREEK
BEARPAW
JUDITH RIVER
CLAGGETT
EAGLE
NIOBRARA
GREENHORN
MOWRY
THERMOPOLIS
MUDDY
SKULL CREEK
DAKOTA
FUSON
LAKOTA
MORRISON
SWIFT & RIERDON
PIPER
CHUGWATER
TENSLEEP
AMSDEN
CHARLES
MISSION CANYON
LODGEPOLE
DEVONIAN, UNDIFF.
INTERLAKE
STONEY MOUNTAIN
RED RIVER
WINNIPEG
DEADWOOD
BASEMENT ROCKS
(AFTER VAN VOAST ET AL, 1977)
EPOCH
MEMBER
DEPTH (METERS)
0
50
100
150
200
250
300
PALEOCENE
TONGUE RIVER
TONGUE RIVER CONT.
LEBO SHALE
TULLOCK
WELL 31-M
BED
PROBABLE DEPOSITIONAL ENVIRONMENT
DEPTH (METERS)
0
10
20
30
40
ROSEBUD OVERBURDEN
ROSEBUD COAL
ROSEBUD MC KAY INTERBURDEN
MC KAY COAL
FLOOD BASIN -
NATURAL LEVEE CREVASS SPLAY
CHANNEL (POINT BARS)
NATURAL LEVEE CREVASS SPLAY
FLOOD BASIN
NATURAL LEVEE CREVASS SPLAY
FLOOD BASIN
LEGEND
AQUIFER
CRYSTALLINE ROCKS
CARBONATE ROCKS
SILTSTONE SANDY SHALE
MUDSTONE SHALE
SANDSTONE
COAL
SOURCES
MONTANA STATE DEPARTMENT OF NATURAL RESOURCES & CONSERVATION 1974
VAN VOAST, HEDGES & MC DERMOTT 1977

Fig. 3. Stratigraphic section in the Colstrip area (Dollhopf and others, 1978b).

feet thick overlie many coal seams. Sedimentary structures in this unit suggest these sands originated as a natural levee and crevasse splay deposit. These sandy units contain about 25 percent more iron than surrounding units. Natural levees form the highest land surfaces in the floodplain. A highly oxidized condition would be expected in this environment, favoring precipitation of iron and perhaps other metals. 4) Sand occurs as linear bodies perhaps deposited as transverse bars in low-sinuosity meandering streams. Rarely, tabular sand bodies 8-10 feet thick extending for over 1000 feet laterally were encountered, and were interpreted as point bar deposits.

Jacobs (1973), Royse (1970) and Cherven (1978) suggest a lower floodplain delta environment for the Paleocene in western North Dakota. Workers in central (Shurr, 1972), and southeastern Montana (Widmayer, 1977) postulate a purely fluvial depositional environment without deltaic influence. Because of the fine grain-size and paleo-current indicators in southeastern Montana, a sediment source several hundred km to the west was suggested.

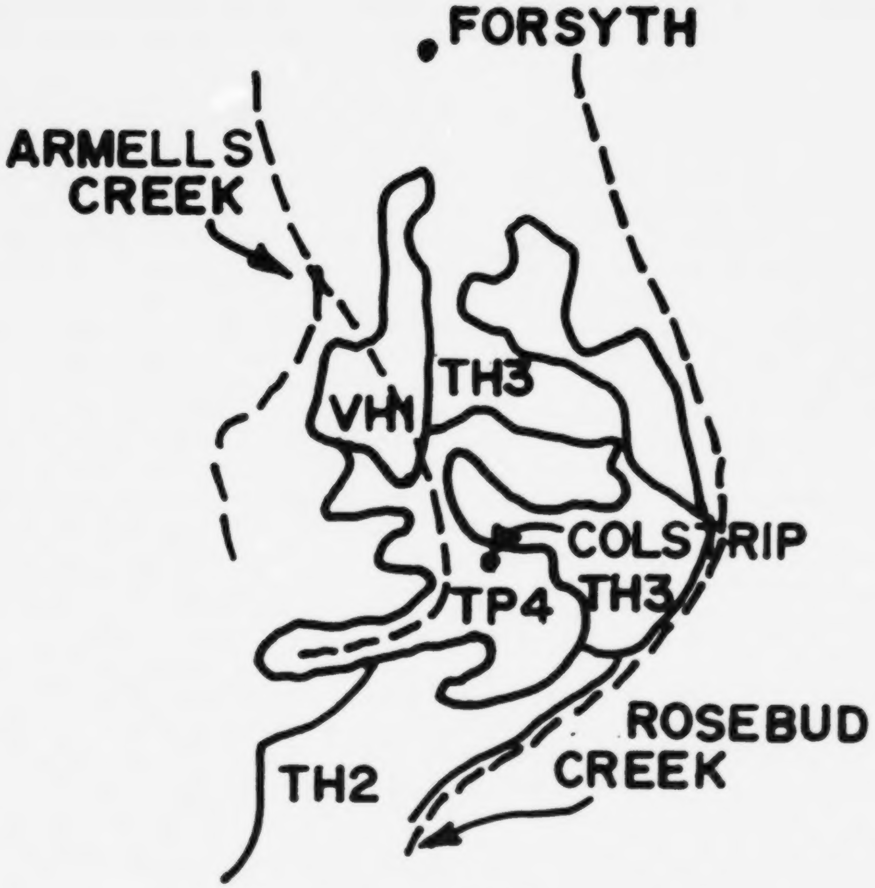
The local geology of Colstrip was described by Dobbin (1930) and Renick (1929). Dollhopf and others (1978a, 1978b) found a complex sequence of sandy and silty deposits overlieing the Rosebud coal seam at Colstrip (Fig. 3). Geometry of these units suggest an origin as point bar, natural levee, and crevasse splay deposits. Sediments are laterally inextensive over tens to hundreds of meters which makes sampling and characterization of overburden extremely complex.

Early Eocene time was a period of strong folding and faulting (Glaze and Keller, 1965) which resulted in many of the present structural features of southeastern Montana. During the Oligocene and Miocene, the area is thought to have been buried by tuffaceous debris from volcanic activity to the west. Regional uplift during the Pliocene accentuated many structural features bordering the Powder River basin. Rejuvenation of streams caused previously buried sediments to be exhumed. Erosion continued until Pleistocene time to form the present landscape. The study area was not covered by Pleistocene continental glaciation, however, changes in climate resulted in downcutting of rivers, formation of river terraces, and rejuvenation of much of the landscape.

Soils

Colstrip lies in a soil transition zone of Aridisols, Alfisols, and Mollisols. Aridisols or desert soils increase in abundance in the southern Powder River basin where the climate is drier. Mollisols, prairie soils, are common in the moister Great Plains of North and South Dakota to the east. Alfisols, or forest soils, occur in the neighboring Big Horn mountains and Black Hills regions. Entisols which are young, undeveloped soils are locally common due to steep slopes and recent fluvial activity.

Simonson and others (1978) recognized a mixture of Camborthids and shallow Torriorthents in the Colstrip area on nearly level to moderately steep dissected bedrock hills and plains (Fig. 4). Soil series typical of these associations included Busby, Cabbart, Riedel, Yamac, Yawdim, and Twilight. North of Colstrip, more clayey soils were recognized where sediment of the



LEGEND

TH2 - Entisols-Aridisols: strongly sloping to steep soils on dissected sedimentary bedrock plains and hills.
Torriorthents (shallow) - Camborthids - Torriorthents

TH3 - Entisols-Aridisols: strongly sloping to steep soils on dissected sedimentary bedrock plains and hills.
Torriorthents (shallow) - Torriorthents - Camborthids

TP4 - Andisols-Entisols: nearly level to moderately steep soils on sedimentary bedrock plains.
Camborthids - Torriorthents

VH1 - predominantly clayey, strongly sloping to steep soils on dissected shale plains.
Torriorthents (shallow) - Camborthids - Natrargids

Fig. 4. Colstrip region soils map showing dominant soil associations (Simonson and others, 1978).

Lebo Shale Member are exposed at the land surface. Aridic Haploborolls and Aridic Argiborolls with weak argillic horizons are also locally common components of the soil landscape.

Properties observed in soils result from the interaction of five soil-forming factors. Climate, organisms, parent material and relief, combine to create a set of processes which modify soils through time. The soils thus formed in turn affect vegetation, hydrology, and land-use patterns. Information on the distribution of different kinds of soils and their individual properties is basic to an understanding of the natural resources of an area.

In the Colstrip area, potential evapotranspiration far exceeds annual precipitation. Run-off during snowmelt and high-intensity summer thunderstorms prevents some precipitation from ever entering the soil profile. As a result, Colstrip area soils are dry in the root zone during much of the growing season. Limited penetration of water into the soil causes an accumulation of lime and other more soluble salts near the base of the root zone. Many coarse-textured soils are dry long enough to have an aridic moisture regime typical of desert soils. Finer-textured soils retain water longer into the summer and have an ustic moisture regime. Some soils at low elevations have a mesic temperature regime while upland soils have frigid temperature regimes (mean annual soil temperature less than 8°C, 47°F). Climate plays an important role in the classification of soils in the Colstrip area.

Vegetation also influences soil development. The Colstrip region is dominated by mixed-grass prairie with Ponderosa pine savannahs in upland areas. Soils under grassland tend to accumulate thick layers of organic matter due to the turnover of fibrous grass root systems (Mollisols). Soils under coniferous forest often have an O horizon of relatively undecomposed litter underlain by a leached, acid mineral A horizon. Argillic B horizons (clay accumulation) are also common in forest soils (Alfisols).

Composition and texture of parent material affect soil properties especially in "young" soils. The Tongue River Member of the Fort Union Formation outcrops through much of the Colstrip area. Sandstone dominates this member with abundant lenses of siltstone. A sheet of clayey shale overlies the major coal seam. Scoria (porcelainite) resulting from combustion of exposed coal caps many buttes in the area. Coarse-loamy and fine-loamy textural classes of soils are dominant locally. Some fine-silty soils occur on colluvium derived from siltstone. Skeletal and fragmental soils are common on top of scoria capped buttes.

Both slope and aspect or exposure, influence soil properties. Due to the sufficiently steep gradient of streams in the region, the weakly consolidated nature of Fort Union rocks, and the youthful landscape; a moderately steep dissected topography has resulted. Keefer (1974) classified the land-surface form in the area "open high hills." Twenty to 50 percent of the land surface has slopes less than 8%, and local relief ranges from 500 to 1,000 feet.

At this latitude (46°N), differences in aspect strongly affect microclimate which influences soil development through vegetation differences. Soils on north-facing slopes are colder and wetter because less incident energy is available to warm and dry these soils. More organic matter accumulates and deeper solums develop on north- and east-facing slopes.

The rate of geologic erosion is high on steep slopes. As a result, only thin A horizons form because soil material is continuously removed from the surface. Steep surfaces are not stable long enough for cambic B horizons (horizon of alteration) to form. The resulting soils are Entisols (Fig. 5).

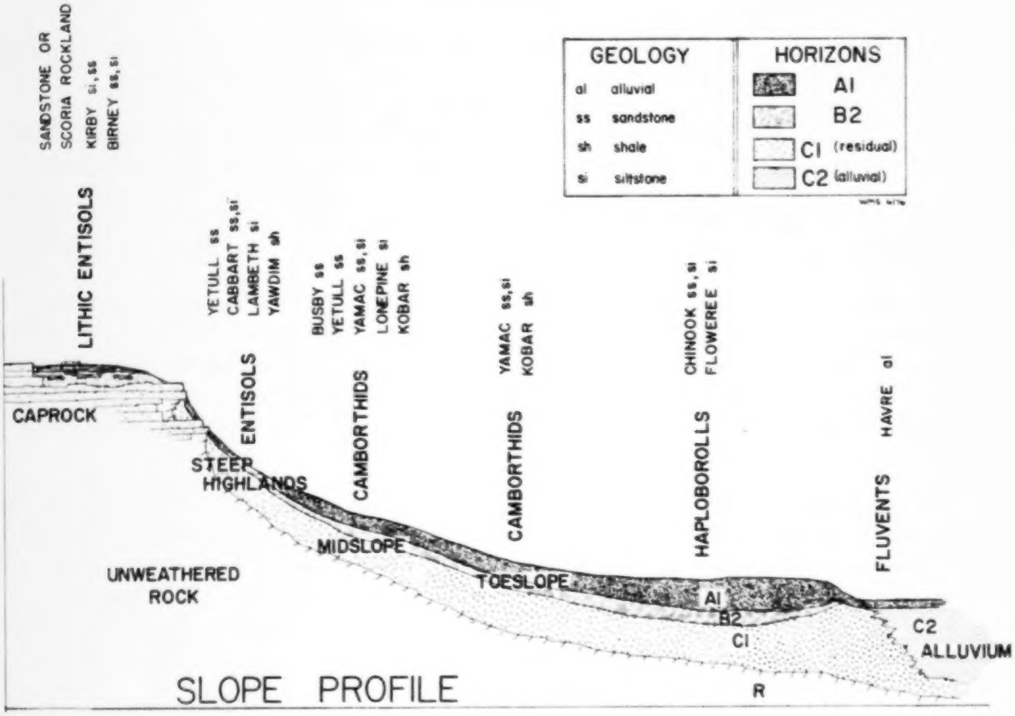

SANDSTONE OR
SCORIA ROCKLAND
KIRBY si, ss
BIRNEY ss, si
LITHIC ENTISOLS
YETULL ss
CABBART ss, si
LAMBETH si
YAWDIM sh
ENTISOLS
BUSBY ss
YETULL ss
YAMAC ss, si
LONEPINE si
KOBAR sh
CAMBORTHIDS
YAMAC ss, si
KOBAR sh
CAMBORTHIDS
CHINOOK ss, si
FLOWEREE si
HAPLOBOROLLS
HAVRE al
FLUVENTS
GEOLOGY
al alluvial
ss sandstone
sh shale
si siltstone
HORIZONS
A1
B2
C1 (residual)
C2 (alluvial)
CAPROCK
STEEP HIGHLANDS
MIDSLOPE
TOESLOPE
UNWEATHERED ROCK
A1
B2
C1
C2
ALLUVIUM
R
SLOPE PROFILE

Fig. 5. Representative slope profile and soil series which develop on various parent materials at each geomorphic position in the Colstrip, Montana area.

On midslopes, surfaces are more stable. Cambic B horizons form and thicker A horizons accumulate creating Borollic Camborthids. On the lowest footslopes where slope flattens, material carried by overland flow from upslope is deposited due to a loss in energy of moving water. Retention of surface run-off in this geomorphic position results in more water moving through the profile than in other soils. Thick mollic epipedons and some argillic horizons may develop. Aridic Haploborolls and Aridic Argiborolls are common. In recent floodplains, materials are periodically reworked which prevents B horizons from forming. These stream-influenced soils are Fluvents.

Climate, organisms, parent material, and relief together create processes which modify soils through time. The length of time a surface is exposed to soil-forming processes thus influences the degree to which many soil properties are expressed. Pleistocene glaciers did not reach the Colstrip area, however, changing Quaternary climates has probably influenced these soils. Uplift of the entire region in Pliocene time began a cycle of downcutting by rivers which has rejuvenated the soil surface in recent times. Most soils in the area are probably near 10,000 years old.

Vegetation

Most native vegetation in southeastern Montana consists of either mixed prairie or coniferous woodland plant associations. Ross and Hunter (1976) list dominant species in the potential climax plant communities in the Colstrip area. These include western and thickspike wheatgrass, little bluestem, needle and thread, green needlegrass, bluebunch wheatgrass, big bluestem, and prairie junegrass. Shrubs should include silver sagebrush, skunkbush sumac, winterfat, and western snowberry. Under grazing pressure blue grama, prairie junegrass, fringed sagewort and others are expected to increase in dominance.

Mixed prairie is dominant in the Colstrip area, and is composed of a diverse mixture of warm and cool season perennial grasses, forbs, and shrubs (Dollhopf and others, 1978). Overgrazing has commonly occurred in the Colstrip area which has promoted development of increaser and invader shrubs, half-shrubs and weedy forbs. Grasslands in the Colstrip area are generally sub-climax in nature.

Mixed prairie sites produce from 1000-1800 kg/ha/year, with mean production near 1250 kg/ha/year (Munshower and DePuit, 1976). Livestock carrying capacity varies from 1.5 to 13 A/Aum. A limited amount of native rangeland has been converted to agricultural land uses including hay pasturage and cereal grain production. The primary land use in the area, however, consists of livestock grazing.

Climate

A continental climate influences the Colstrip area. The extreme range in recorded temperatures from -40°F to 111°F characterizes this climate. Despite high summer temperatures, large diurnal temperature fluctuations moderates mean daily temperature to 71.5°F during July, the warmest month. Average annual precipitation for the period 1941-1970 was 40.1 cm (15.8 inches) (NOAA, n.d.). Thirty centimeters of precipitation falls during the April to September growing season with 15 cm coming early in the growing season. Summer precipitation occurs as showers and high intensity thunderstorms. Annual precipitation can deviate substantially from the average 15.8 inches. Only 8.6 inches fell in 1934 while 24.7 inches was recorded in 1944 (Table 1). Geologic evidence accumulated in the northern Rocky Mountains, and mid-continent regions suggest that the climate has changed dramatically in the last 10,000 years during the time when most Colstrip soils were forming (Morrison, 1965). Following retreat of the Wisconsin glaciers and again 4,000 years ago the climate was colder and wetter than than today, while during the "altithermal" period of 6,000 years ago, a warm dry climate existed. The climate today is somewhat cooler and wetter than during the Altithermal period.

Table 1. Annual precipitation at Colstrip, Montana for the years 1928-1977 (NOAA, nd).

YEAR	PPT (in.)	YEAR	PPT (in.)	YEAR	PPT (in.)
		1941	17.7	1962	15.3
		1942	18.3	1963	17.8
		1943	17.7	1964	18.5
		1944	24.7	1965	14.3
		1945	13.8	1966	13.0
		1946	20.9	1967	17.2
		1947	11.3	1968	19.8
		1948	16.4	1969	17.6
1928	12.1	1949	11.9	1970	15.6
1929	12.0	1950	14.6	1971	19.2
1930	12.0	1951	14.8	1972	16.6
1931	11.3	1952	10.1	1973	16.9
1932	20.4	1953	19.3	1974	18.4
1933	18.2	1954	11.3	1975	
1934	8.6	1955	17.5	1976	12.7
1935	15.7	1956	13.6	1977	16.1
1936	10.9	1957	18.4		
1937	12.0	1958	17.0		
1938	12.3	1959	10.5	average	15.4
1939	14.3	1960	10.4		
1940	19.7	1961	14.7		

Land Use

The dominant land use in the Colstrip area is livestock grazing on the extensive grasslands of the region. An increasing amount of land around the townsite is being used for urban development including single and multifamily dwellings, schools, commercial developments, parks, and roads. Power generating plants and associated settling ponds, cooling ponds, pipelines, and service roads occupy several hundred acres. Many small tracts in broad valleys are used for cereal grain production. Finally, a limited amount of land along subirrigated perennial stream courses is used for dryland production of alfalfa and other hay crops.

Site Selection

Research sites for intensive study were chosen to represent spoils deposited throughout the history of mining at Colstrip. In addition, undisturbed sites were selected for study of baseline soil characteristics and processes. Changes in mining methods through time, depth and type of overburden moved, and reclamation methods applied resulted in a variety of spoils with widely varying characteristics to choose for study. Differences in soil development processes and land use patterns similarly caused a diversity of undisturbed sites. Two criteria were used to select research sites: 1) sites should extend over the widest variation in properties observed and 2) some sites should be selected to represent the modal or most common characteristics.

Research sites were selected during preliminary field investigations by personnel familiar with undisturbed soils of the area, mining history, and reclamation methods. Fifteen sites were chosen for intensive study. These included 1) five undisturbed native range sites on common soils of the region, 2) five sites on old spoils which were formed between 1928 and 1948, and 3) five sites on new spoils in a recently active mine area where modern reclamation techniques were applied (Fig. 6).

A detailed description of each site on spoils was prepared including type of overburden material, mining methods, age, seeding mixtures, fertilization, other reclamation techniques, present vegetation and management. Characteristics of undisturbed sites included type of material, soil classification, landscape position, and dominant vegetation (Table 2).

A companion study to evaluate vegetational succession on mine spoil shared many of the research sites (Sindelar and Plantenberg, 1977). Detailed description of vegetation composition, and production were made available for comparison with soil properties.

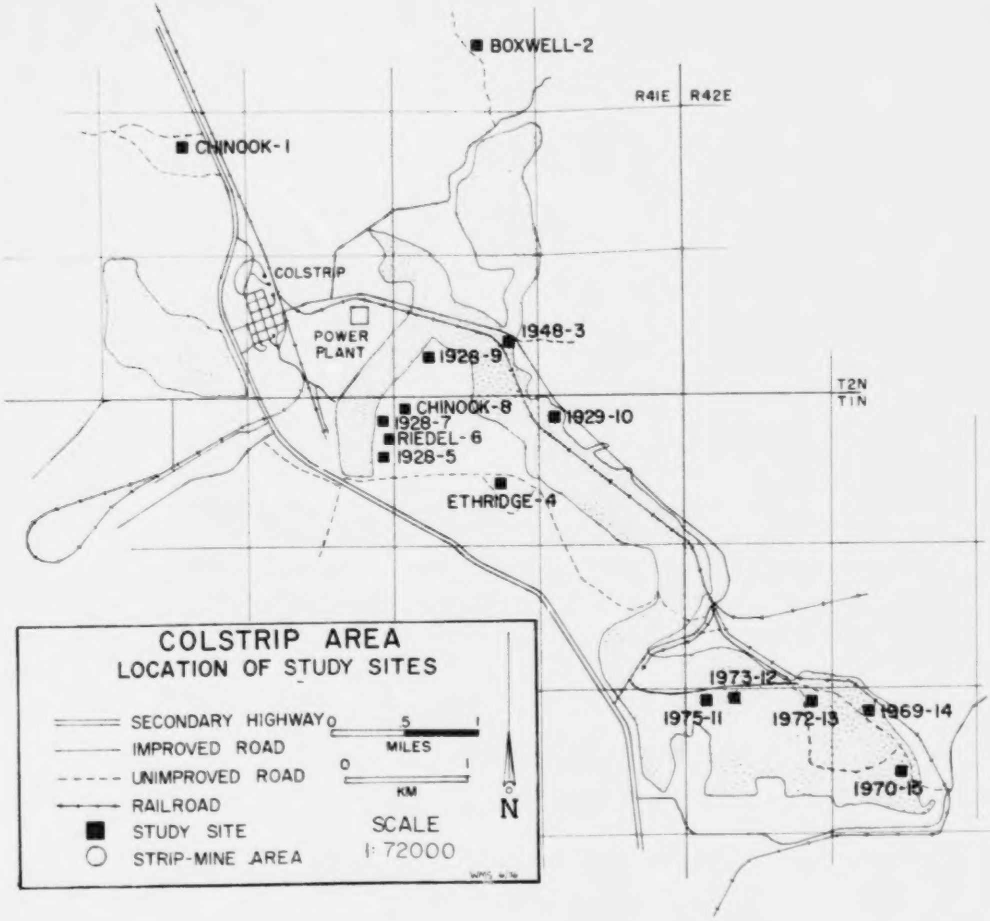

BOXWELL-2
R41E
R42E
CHINOOK-1
COLSTRIP
POWER PLANT
1948-3
1928-9
T2N
T1N
CHINOOK-8
1929-10
1928-7
RIEDEL-6
1928-5
ETHRIDGE-4
1973-12
1975-11
1972-13
1969-14
1970-15
COLSTRIP AREA
LOCATION OF STUDY SITES
SECONDARY HIGHWAY
IMPROVED ROAD
UNIMPROVED ROAD
RAILROAD
STUDY SITE
STRIP-MINE AREA
0
.5
1
MILES
0
1
KM
SCALE
1: 72000
N

Fig. 6. Location of 15 research sites near Colstrip, Montana. The site names represent either the soil series if natural soils, or date of last disturbance if minesoils.

Table 2. Description of origin, characteristics and management of research sites. Sites were chosen to represent the diversity of characteristics as well as typical aspects of minesoils and undisturbed soils in the Colstrip area.

			Reclamation Treatment		
Site	Soils	Vegetation	Seed Mix	Fertilization	Other
Chinook-1	This site is located in a toeslope landscape position on a north-facing slope. The soil is an Aridic Haploboroll and has a buried soil at 1 m. It is a very youthful soil. The site was cultivated at some time in the past.	A mixture of grasses and forbs is dominated by *Stipa comata*, *Koeleria cristata*, and *Bouteloua gracilis*. *Bromus* sp. is common locally around pocket gopher holes.	none	none	none
Boxwell-2	This site lies in a midslope position on an upland surface. The soil is a Haploboroll and has a well expressed C_{ca}	*Stipa comata*, *Aristida longiseta*, and *Tragopogon dubius* dominate the stand. Annual grasses are abundant.	none	none	none
Ethridge-4	The soil is a Borollic Haplargid. It lies in a toeslope position and has developed in colluvium from shale. Gypsum and soluble salts are present below 1 m. The site was cultivated some time in the recent past.	*Artemesia cana*, *Gutierrezia sarothrae*, and *Aristida longiseta* are dominant components of the vegetation.	none	none	none
Riedel-6	The soil is a shallow Borollic Camborthid and has a paralithic contact at 50 cm. It is on a heavy level interflure and has developed in weakly consolidated sandstone.	*Bouteloua gracilis*, *Koeleria cristata*, *Stipa comata* and several forbs dominate this overgrazed site.	none	none	none
Chinook-8	This site is in a middle backslope position. The soil is an Aridic Haploboroll and has developed from sandstone colluvium. The solum is mixed due to rodent burrowing activity.	*Bouteloua gracilis*, *Koeleria cristata*, *Stipa comata*, and *Calamovilfalongifolia* are dominant grasses. *Ambrosia psilostachya* and other forbs are common.	none	none	none
1948-3	This soil contains coal-rich material or "gob" from the pit bottom. Coal fragments and shale are common.	*Poa pratensis*, *Stipa comata*, and several other forbs, and shrubs are dominant.	none	none	none
1928-5	The site was created in 1928 and consists of excess surface overburden material removed from the mine area. It is nearly level and was derived from sandstone and colluvium. Soft rock fragments are common below 10 cm.	*Artemesia dracunculus* and annual grasses dominate the stand.	none	none	none
1928-7	Same as 1928-5	*A. dracunculus* and *A. cana* along with *Stipa comata* and *Agropyron smithii* are dominant.	none	none	none
1928-9	Same as 1928-5	Several perennial grasses and forbs are common on this site.	none	none	none
1929-10	The site was created in the same way as 1928-5 but the material is more clayey. Shale fragments are common.	*Agropyron spicatum* is dominant with other perennial grasses, forbs, and shrubs.	none	none	none
1975-11	This nearly level site was topsoiled with 10 cm of sandy material. The upper 80 cm of the solum was deposited with scrapers. Scoria fragments are common at the surface. Shale-rich layers are common throughout the profile.	Vegetation was sparse in 1976 and 1977. Temporary stabilizers and *Salsola kali* were dominant.	Mixture of 10 grasses, 1 shrub, and 2 legumes was drill seeded.	185 kg/ha of (16-20-0) fertilizer applied on 4/76	none
1973-12	No topsoil was applied to this site. Material was deposited with bulldozers. Sandstone fragments are common.	*Agropyron cristatum*, *A. elongatum*, *Bromus inermis*, and *Medicago sativa* comprise most of the vegetation.	Mixture of 23 grasses drill seeded.	188 kg/ha of (16-20-0) applied in fall, 1975 or spring, 1976	gouging surface manipulation
1972-13	Ten to 15 cm of topsoil was applied on this nearly level site . The upper 100 cm of the profile was deposited with scrapers. Shale-rich layers are common in the profile.	Similar to 1973-12	3 grasses, legume, and wheat were broadcast seeded. A broad seed mix with 24 species was drilled.	5/72 (84-56-0) kg/ha of N, P_2O_5, and K_2O; 2/73 (90-121-0); 4/74 (90-121-22).	gouged
1969-14	Old unregraded spoils from previous mining were regraded by bulldozer in 1969. No topsoil was applied. Shale and coal fragment are common.	*Agropyron dasystachyum*, *A. elongatum*, and *Chrysothamnus viscidiflorus*	Ten grasses, 2 shrubs, and 3 legumes were drill seeded.	4/70 112 kg/ha of (16-20-0)	none
1970-15	This nearly level site was deposited by bulldozer. No topsoil was applied. Sandstone rock fragments are common.	Similar to 1973-12	Twelve grasses, 2 shrubs, and 3 legumes were drill seeded.	11/70 (84-179-67); 1/72 (168-121-0); 4/74 (90-121-0); 7/74 (45-56-22)	none

SECTION 6

MATERIALS AND METHODS

Fifteen sites were chosen for intensive study on old spoils, new spoils, and undisturbed native range. Fences were constructed at each location to protect research areas from disturbance by livestock and to comply with federal regulations governing use of radioactive isotopes. Research activities were located within the fenced exclosures as shown in Fig. 7.

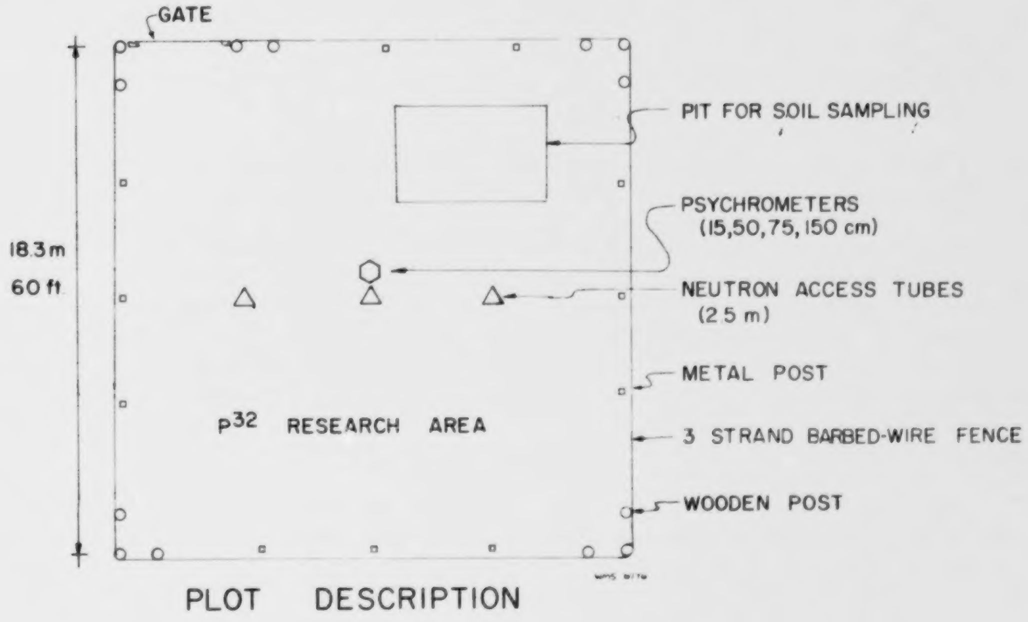

GATE
PIT FOR SOIL SAMPLING
PSYCHROMETERS
(15,50,75,150 cm)
18.3m
60 ft
NEUTRON ACCESS TUBES
(2.5 m)
METAL POST
P32 RESEARCH AREA
3 STRAND BARBED-WIRE FENCE
WOODEN POST
PLOT DESCRIPTION

Fig. 7. Arrangement of research exclosures.

Soil Characterization

Excavations two meters deep were made with a backhoe at each site to allow detailed description of soil pedons and collection of bulk soil samples from the profile face (SCS, 1971). The National Soil Survey Laboratory in Lincoln, Nebraska and the Montana SCS state office assisted in description and sampling of each pedon in August, 1976. Pedons were described in the field by experienced soil scientists using standard terminology used in soil survey (Soil Survey Staff, 1962). Bulk samples were collected from each horizon for laboratory analysis. In addition, samples were collected separately from narrow depth increments near the soil surface. Detailed surface sampling was intended to isolate small changes in soil properties which may have occurred only in the upper few cm of spoils during 50 years of soil development. Native soils were identically sampled to insure proper comparison between minesoils and undisturbed soils. Undisturbed clods were obtained from selected horizons for measurement of bulk density, and water retention; and for preparation of soil thin sections (Brewer, 1976).

The National Soil Survey Laboratory in Lincoln, Nebraska provided standard soil analysis of all pedons. Analysis performed on all samples included mechanical analysis; $CaCO_3$ equivalent; pH 1:1 in H_2O; pH 1:2 in $CaCl_2$; organic carbon; total nitrogen; and pH, water content, and electrical conductivity of saturated paste. For selected samples the following data were obtained: water retention at 0.3, and 15 bars; bulk density of ovendry, and 0.3 bar sample; clay-sized $CaCO_3$; extractable ions; saturated paste resistivity; and total soluble salts. Clay mineral abundance was estimated for two to four samples from each pedon. Semi-quantitative estimates of clay mineral species was based on comparison of peaks obtained from x-ray diffraction of the oriented clay fraction. Atterberg limits were measured on a few samples. Standard methods used by the Soil Survey Laboratory were followed in obtaining the analyses listed above (SCS, 1972).

Additional analyses were performed at Montana State University on selected pedons which were most representative of native soils; and old, and new spoils. Total phosphorous was determined using the method of Muir (1952) as suggested by Syers and others (1968). Inorganic phosphorous was fractionated according to the procedure of Chang and Jackson (1957) into Al-P, Fe-P, Ca-P, reductant soluble P, and occluded Al-P. Phosphorous concentration in each extract was determined colorimetrically according to John (1970). The difference between the sum of inorganic P fractions and total P was assumed to represent organic P. Analysis of DTPA extractable Cu, Fe, Zn, Mn, (Follett and Lindsay, 1971), Ni, Cd, and Pb was also performed. Modifications of the DTPA procedure were observed (Soltanpour and others, 1976).

A quantitative estimate of the "parent material" of each minesoil was obtained by measuring the content of different rock types at 50 cm in each minesoil pedon. A point count technique was used to measure the volume of differing materials (Daniels and others; 1968). Three sets of 100 counts each were averaged to obtain an estimate of the "parent material" for each pedon.

Rock fragment content decreased towards the surface of minesoils. This decrease suggested that rapid weathering of some rock fragments was occurring. To estimate the susceptibility to weathering of different kinds of rock fragments, pebble counts and visual volume estimates of fragments were made at several depths in spoils.

Water Movement

Seasonal patterns of water movement were evaluated by measuring soil water content and soil water potential at monthly to bi-weekly intervals from

June, 1976 to September, 1977. Daily precipitation records for the period were obtained from a NOAA weather station at Colstrip. Other components of the water balance; run-off, deep percolation, and evapotranspiration were not directly measured.

Water content was measured by the neutron moderation method (Long and French, 1967). A Troxler model 1255 neutron probe with an americium-berylium neutron source was used with a model 2601 Troxler scaler for all measurements. Three access tubes two inches in diameter were installed at each of 15 sites to a depth of 210 cm. Volumetric soil water content was measured 22 times during the study. Water content was measured at 15 cm intervals from 0-90 cm, and at 30 cm intervals below 90 cm. Factory calibration was used to calculate water content from field measurements. Changes in the total amount of water stored in soils, and patterns of water removal and recharge were investigated.

Double-junction thermocouple psychrometers (Chow and deVries, 1973) were installed to measure soil water potential and soil temperature. Psychrometers were located at 15, 50, 90, and 150 cm and were read at the same time as the neutron probe. The sensors were oriented horizontally to avoid temperature gradients which would bias measurements (Wiebe and others, 1977). A Kiethly model 155 microvoltmeter and Emco switchbox were used to read the psychrometers. During the winter of 1976-1977 all psychrometers were returned to the lab for cleaning and calibration over NaCl solutions of 2.3, 13.4, 31.5, and 45.5 bars. Psychrometers were read three times over each solution at 20°C. The calibration results were fit to a curve of the form.

$$E = A\ (1-e^{.000726\ \Psi})$$

where E equals the psychrometer reading in microvolts, Ψ is the theoretical potential of the solution, and A is statistically derived by a least squares curve-fit. The form for this equation was derived from Rawlins (1972) who calculated the EMF response of an "ideal" psychrometer:

$$EMF = 882.6\ (1-e^{Vw\ \Psi/RT})$$

Values of A which were empirically derived averaged 692 with a standard deviation of 107, and were in most cases less than the theoretical value of 882.6. A theoretical correction for variations in ambient temperature was used to adjust water potential measurements obtained in the field. A factory calibration was used to calculate soil temperature from psychrometer readings.

Infiltration velocity was determined at three positions on each site in August, 1976. A rainfall simulator which applies water droplets over a 0.31 m^2 area from 50 cm above the soil surface was used (Meeuwig, 1971). A flowmeter registered the rate of water application which simulates an intense storm in volume, but not raindrop impact. Run-off was measured at four-minute intervals. The difference between application rate and run-off was equal to the infiltration rate.

Root Biomass and Activity

Three different methods were used to characterize root systems at the research sites. The number of exposed roots exposed in a standard area of soil were counted; roots from three depths were sampled, separated from soil, and weighed; and radioactive phosphorous, P^{32}, was injected at selected depths. Uptake of P^{32} by roots was indicated by radioactivity of plant tops measured at several dates after injection. This combination of methods allowed measurement of root biomass and also seasonal dynamics of root activity.

Standard field description of soils include an estimate of root abundance as absent, few, common, or many. These terms correspond to a range in the number of roots exposed in a dm^2 area (Table 3).

Table 3. Abundance of roots by number and size (from Soil Survey Staff, 1975).

Class	Very Fine (< 1 mm)	Fine (1-2 mm)	Medium (2-5 mm)	Coarse (5-10 mm)
	average number per square decimeter			
Few	< 10	< 10	< 1	< 1
Common	10-100	10-100	1-10	1-5
Many	>100	>100	>10	>5

A more accurate estimate of root abundance was required for this study than few, common, or many. Therefore, the actual number of roots in each size class were counted at five randomly selected locations at each of three soil depths; 10 cm, 50 cm, and 100 cm. The above classification of root sizes was expanded to include microfine roots from the smallest visible diameter to 0.5 mm in size. Results of this counting method were correlated with actual root weights so root count data which are quickly obtained in the field can be correlated to root biomass which is more physically meaningful. Schafer and Nielsen (1978) report additional details and results of the root count method.

Decimeter cubes of soil and roots were collected at each location where roots were counted as in the previous section. These soil cubes were returned to the lab where roots were washed free of soil by washing on a 1 mm sieve. Roots collected from each cube were weighed after 48 hours drying at 60°C and again after ignition at 600°C overnight. Root weights are reported on an ash-free basis.

A radioactive tracer, P^{32}, was also used to investigate the belowground portions of plants (Boggie, and others, 1958; Burton and others, 1954, and Lipps and others, 1957). Injections of P^{32} were made at approximately one foot intervals to seven feet. If plant tops exhibited an increase in beta radiation after injection, it was assumed that growing roots were present at the injection depth.

On June 10-11, 1976, six P^{32} injections were made at 13 research sites. The tracer was placed at 15, 46, 76, 107, 137, and 183 cm. Injection holes were prepared by driving a tempered steel rod to the desired depth. Holes were spaced 3 m apart to avoid interference between injection sites. Injection sites were selected near several different dominant plant species so that P^{32} would be available for uptake by existing root systems.

The P^{32} solution was prepared by diluting carrier-free P^{32} in HCl solution with 2.2×10^{-3} $\underline{N}$ KH_2PO_4 and 2.4×10^{-2} $\underline{N}$ HCl to a final concentration of 0.10 mCi ml^{-1}. A leur-lok syringe was connected to a suitable length of steel tubing to deliver 2.0 ml of tracer solution at the desired depth. After injection of P^{32}, the tubing was rinsed with 5 ml of distilled water and 5 ml of air before removing it from the hole. This method results in a 5-10 cm diameter radioactive sphere of soil (Ferguson, 1976).

Radioactivity of plant tops within 1 m of the injection hole was measured *in situ* on June 27, July 14 and August 10. Beta radiation was measured with an anti-coincidence Geiger-Muller (G-M) detector and scaler (Duncan and Ohlrogge, 1957) designed and constructed for this study (Fig. 8). The Geiger-Mueller detector and counter were designed by Dr. J. Amend, Chemistry Dept., MSU. The engineering research lab unit built the field unit.

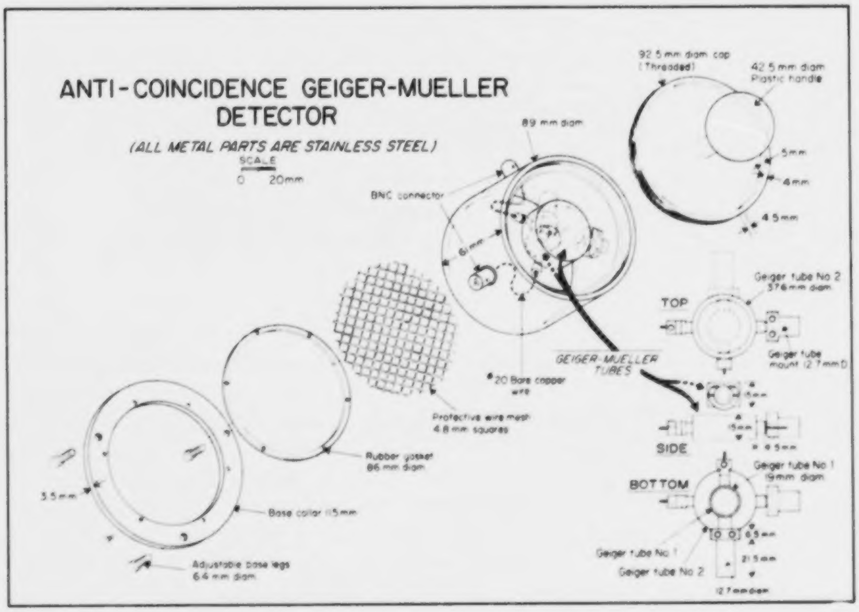

ANTI-COINCIDENCE GEIGER-MUELLER DETECTOR
(ALL METAL PARTS ARE STAINLESS STEEL)
SCALE
0 20mm
92.5mm diam cap (Threaded)
42.5mm diam Plastic handle
89 mm diam
5mm
4mm
4.5mm
BNC connector
61mm
Geiger tube No 2 37.6mm diam
TOP
Geiger tube mount 12.7mm D
GEIGER-MUELLER TUBES
20 Bare copper wire
15mm
15mm
SIDE
4.5mm
Protective wire mesh 4.8mm squares
Rubber gasket 86mm diam
Geiger tube No 1 19mm diam
BOTTOM
3.5mm
Base collar 115mm
6.5mm
Geiger tube No 1
Geiger tube No 2
21.5mm
12.7mm diam
Adjustable base legs 6.4mm diam

Fig. 8. Anti-coincidence detector.

A schematic diagram of the detector and circuitry appears in Fig. 9. Use of an anti-coincidence system allowed accurate field readings by reducing error from background radiation. A Thyac G-M survey meter was used to locate radioactive plants near the injection hole. Three one-minute counts were taken with the anti-coincidence detector on each date. If plants were only slightly radioactive, one ten minute count was taken. After the last field measurements in 1976, plants were harvested to obtain readings by Liquid Scintillation Counting (LSC) in the lab. Plants were dried at 110°C for 24 hours, ground, dry-ashed, dissolved in a LSC emulsifier and counted in a Tri-carb LSC spectrometer. In this way field readings with the anti-coincidence detector were correlated with standard LSC readings (Wyatt, 1978).

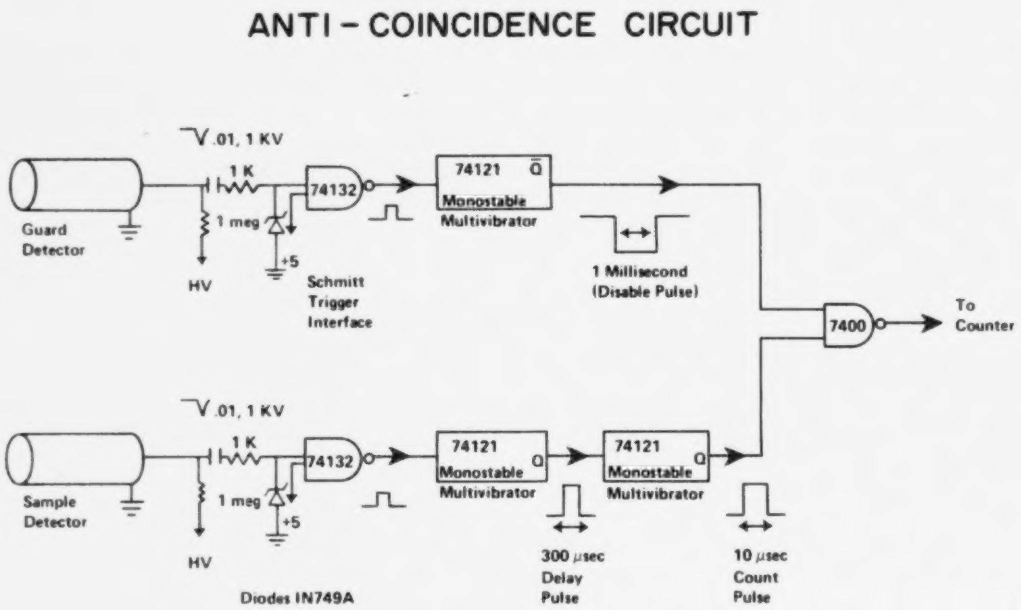

ANTI-COINCIDENCE CIRCUIT
.01, 1 KV
1 K
1 meg
74132
74121
Q̄
Monostable Multivibrator
Guard Detector
HV
+5
Schmitt Trigger Interface
1 Millisecond (Disable Pulse)
7400
To Counter
.01, 1 KV
1 K
1 meg
74132
74121
Q
Monostable Multivibrator
74121
Q
Monostable Multivibrator
Sample Detector
HV
+5
Diodes IN749A
300 μsec Delay Pulse
10 μsec Count Pulse

Fig. 9. Schematic diagram of circuitry in anti-coincidence detector.

In 1977, 10 research sites were injected with P^{32}. Three injections were made at all depths in each of three sites which were representative of native range, old spoils, and new spoils. This replication allowed the statistical reliability of the radioactivity measurements to be estimated. Most injections were made on March 24, 1977; however licensing requirements limited the amount of undiluted P^{32} which could be kept on hand. A second injection was therefore made on April 6, 1977 to obtain the desired number of sample sites. 0.2 m Ci of P^{32} was placed at the same depths as 1977, but in addition an injection was made at 214 cm. Plant radioactivity was measured as in 1976 on the following dates; April 16, April 30, May 14, May 31, June 17, July 9, July 19, and July 31. Several plants outside the injection area were also measured to obtain background levels of beta radiation.

Radioactive phosphorous has a half-life of 14.3 days. When plant radioactivity is measured *in situ* on successive dates, some of the radiation recorded on a given date could be caused by residual P^{32} retained in the plant since the previous measurement date. Since the decay rate of P^{32} is known, however, this residual radioactivity could be calculated and subtracted from field measurements. The corrected field count would give an indication of P^{32} taken up only since the previous injection. Further correction of the field counts could be made for P^{32} decay since the original injection. This final value would allow comparison of uptake for each time increment between injections. If we assume that changes in radioactivity in plant tops are caused by differences in root growth rate or "root activity," then comparison of corrected radiation measurements would provide a measure of the seasonal dynamics of root growth of individual plant species at different depths. A general view of the belowground functioning of each site could also be obtained. An equation was derived to make these corrections (App. C).

Microbiological Activity

Sample collection: Soil samples were collected on August 9-12, 1976, on June 10, 1977 and on October 10, 1977. The methods of taking each set of samples follows.

August 1976 samples were portions of the samples taken by a collaborative team effort from freshly dug pits. The sampling depths and manner of sampling were dictated by the necessity for soil classification and analysis and are described elsewhere. For microbial activity, portions of the sieved and mixed samples were placed in plastic bags and immediately frozen on dry ice. This was done within 5 to 10 minutes of sample preparation and there should have been very little loss in microbial activity. A total of 118 samples were collected.

Samples were collected in June, 1977 with a 5.1 cm (2 inch) soil corer to a depth of 30.5 cm (12 inches), in triplicate at each site. Each of 45 cores was divided into three 10.2 cm (4 inch) sections (designated as top, middle and bottom sections), placed in plastic bags and frozen on dry ice within three minutes of coring.

Samples from 54 cores were taken in an identical manner in October, 1977. An additional 14 soil samples were collected with a preponderance of plant roots in order to determine ATP activity in free soil, rhizosphere and rhizoplane samples. These 14 samples were dug with a spade to an approximate depth of six inches but with no regular dimensions. One gallon samples were taken to obtain a clump of roots of a single plant with as much adhering soil as possible. These samples were frozen on dry ice as soon as collected.

All samples were kept in a freezer chest with dry ice during transportation to the laboratory and then stored in a freezer.

Microbial activity: ATP was used as the indicator of microbial activity. Each soil sample was treated as follows: Soils were blended in a P-K twin shell dry blender. A sample was removed to determine dry weight equivalent, this being one gram for the 1976 samples and five grams for the later samples where more soil was available. Triplicate samples, 100 grams when possible, were weighed out and the ATP extracted. This was accomplished by mixing with boiling 0.1M $NaHCO_3$ in a one gallon Waring blender using 18 parts by weight of bicarbonate solution to one part by weight of soil. From each mixture of soil and bicarbonate, triplicate samples of 19 ml each were removed by pipette and centrifuged at 12,500 rpm and at 0-5 C for ten minutes to remove particulate matter. The supernate was decanted into 27 ml of iced pH 7.8 Tris buffer, mixed by inversion of the tubes five times and an aliquot then placed in a cuvette and frozen in a dry ice-acetone bath. This gave nine measurements of the ATP for each depth at each site. ATP was measured with the Dupont luminescence biometer standardized against known ATP preparations and results were expressed as femtograms ATP per gram dry soil. (1 fg = 1 x 10^{-15} grams).

For separation into free soil, rhizosphere and rhizoplane the following procedure was adopted: Approximately 100 g cores were spread on a paper and the roots picked out by hand, leaving the free soil. The roots were washed in a weighed volume of water. The material removed by washing was designated rhizosphere and the washed roots designated rhizoplane. Dry weights were calculated for all three fractions and ATP was expressed both as fg ATP/g material (free soil, rhizosphere or rhizoplane) and as percent of the total ATP in the 100 gram sample.

SECTION 7

SOIL DEVELOPMENT AND CHARACTERIZATION

Chemical and physical analysis of soils in native range, old spoils, and new spoils illustrates the soil genesis process in spoils, and also quantifies broad differences between minesoils and native soils. Minesoils are different from surrounding soils not only because of their youth but also because of their unique origin through the mining process.

Colstrip History

Mining methods, reclamation techniques, types of equipment, and even climate have changed during the period of time when coal has been mined at Colstrip. These changes along with soil genetic changes have resulted in striking differences between old and new spoils.

Coal was first mined commercially at Colstrip in 1924 by the Northwestern Improvement Co. to supply coal for engines of the Northern Pacific Railroad. Foley Brothers Construction performed the mining under contract to Northwestern Improvement (Fig. 10). Mining ceased in the mid-1950's but resumed in 1968 when the Western Energy Company purchased the mine and the town of Colstrip. During 1971 to 1973 Burlington Northern Railroad leveled and reseeded many spoils formed during the early mining period. Several undisturbed remnants of spoils from 1928 and 1929 were used for this study.

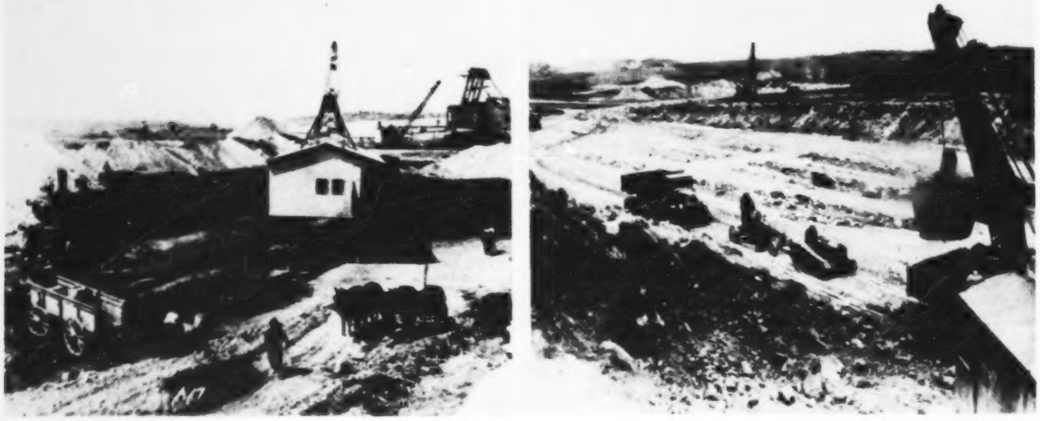


Fig. 10. Foley Bros. mining operation at Colstrip in 1928.

Many of these spoils were removed by mining in 1978.

Coal shovels used in the early mining period could remove a maximum of 14.3 m (47 feet) of overburden material. In areas where this thickness was slightly exceeded, excess overburden was removed with smaller shovels; side-dumping haul trucks then deposited the material outside the mine area (Fig. 11). The first overburden removed was deposited near the crest of a ridge. Later material was deposited beyond the initial overburden until a wedge-shaped platform of spoils was constructed that was flat on top (Fig. 11).

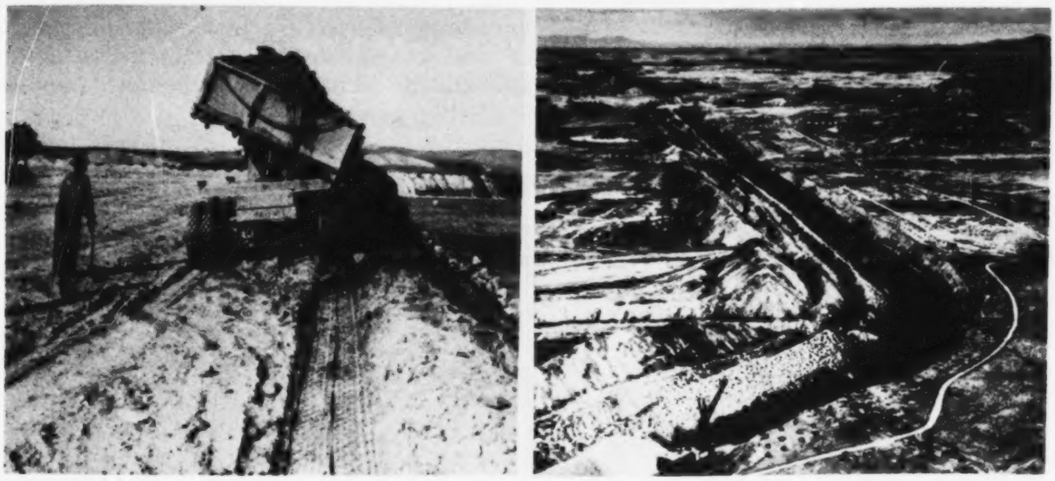


Fig. 11. (Left) spoil platform being deposited with a side-dumping Mack truck in 1929, (Right) material for 1929-10 site was stripped from the right side of photo and dumped on the left.

The flattened configuration provided an ideal setting for a soil genesis study because it prevented the accelerated erosion common on the "normal" unregraded spoils of that period (Fig. 36). Unregraded spoils deposited during early mining had more clayey textures and steeper slopes than flattened spoils of excess overburden investigated in this study.

Excess overburden from the top one to eight meters of the geologic column represented the parent material of flattened spoils constructed during 1927 to 1931. This material was derived in part from existing soils while the remainder was from the oxidized portion of the overburden above any aquifers. Some old spoils examined in this study had up to 10 percent by volume dark-colored material derived from A horizons of pre-existing soils. The origin of old spoil material is in direct contrast to newer spoils. In recent mining, large draglines were used which have a tendency to invert the geologic column. Materials were derived largely from below the oxidized zone of the overburden. A thin veneer of salvaged "topsoil" was often placed on top of newer spoils. These differences in origin might be expected to result in differing chemical characteristics of old and new spoils. Much care needs to be taken in this study before differences between spoils can be attributed to genetic processes.

In accordance with current reclamation law, many steps are involved in the reclamation of strip-mined lands. Spoils are routinely regraded, topsoiled, deep-chiseled, fertilized, and seeded to attain a vegetative cover. By contrast, no reclamation was practiced on old spoils. Revegetation occurred only by invasion and natural succession. The proximity of seed sources and the intensity of grazing were, therefore, critical to the revegetation of old spoils (Sindelar and Plantenberg, 1978).

Old spoils were deposited in 1927 to 1929. Precipitation was below normal from 1929 to 1931 which could have slowed or prevented development of a significant plant cover. The "great drought" occurred a short time later from 1934 to 1938 (Table 1). Precipitation was far below normal, and warm dry winds caused large dust storms. Colstrip was extremely susceptible to the drought and dust storms because of sandy soil textures and overgrazing by sheep and horses beginning in 1880. Many natural soils in the area are noncalcareous throughout the solum except for a thin calcareous layer at the surface which may be dust deposited during the mid-1930's. An aerial photo of Colstrip taken in 1931 reveals that the old spoils were nearly devoid of vegetation (Fig. 12). The influence of vegetation represents one of the most important soil-forming factors, expecially during early stages of soil genesis. We can assume that the soil development process was extremely slow during the

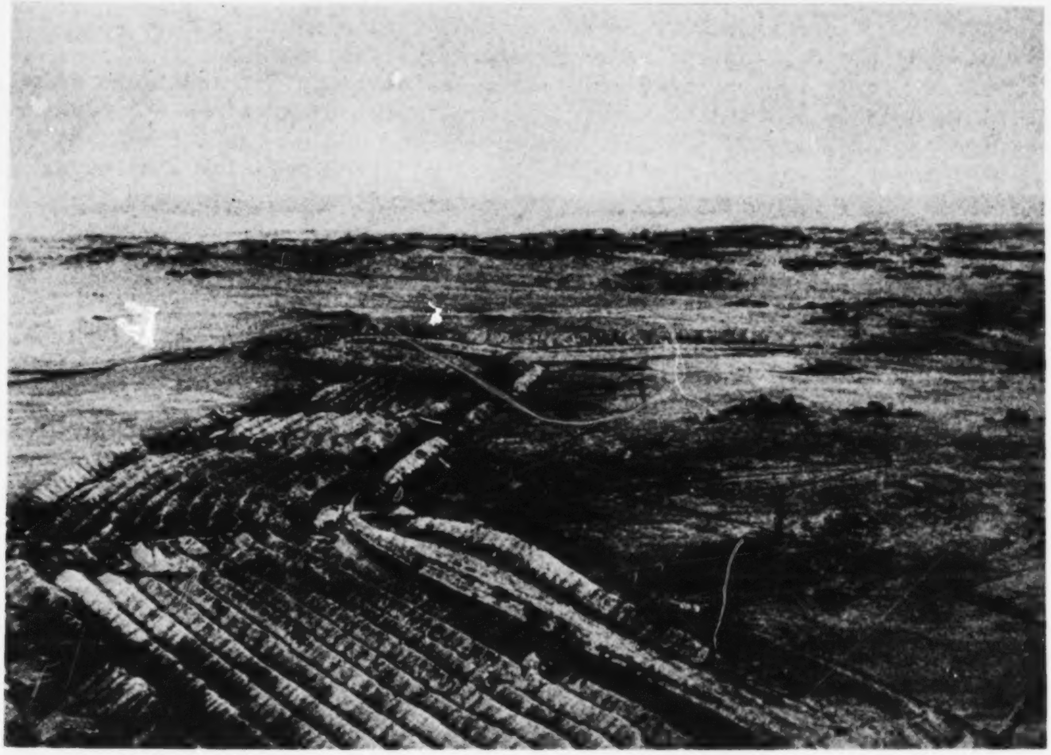


Fig. 12. 1931 Aerial photo taken of 1928 spoils showing vegetation.

10 years immediately following deposition of the old spoils because of a scarcity of vegetation.

Soil Morphology

Natural soils and minesoils are distinctly different in gross morphology. Natural soils have formed from homogeneous parent material within the scale of a pedon which is evident in the C horizon as weathered sandstone and siltstone, or colluvium derived from these materials. Soil development processes have modified these parent materials so that distinct horizons have developed. Thin A horizons 10 to 20 cm thick have formed with dark colors and granular structure. From about 15 to 50 cm, natural soils usually have a cambic B horizon which has higher color value and chroma than the A horizon. Prismatic or subangular blocky structure has formed in this horizon. Some natural soils have accumulated enough clay in the B horizon for it to be termed argillic. Calcium carbonate has been leached from natural soils to form a C_{ca} horizon with segregated lime below 50 cm. Boxwell-2 and Ethridge-4 (Appendix A) are natural soils which exhibit profile differentiation caused by soil development. Other processes such as rodent burrowing tend to homogenize soils and destroy distinct horizons (Riedel-6 and Chinook-8).

Minesoils are formed in heterogenous parent material (Table 4). A mixture of sandstone and siltstone fragments of varying hardness is deposited in a matrix of loamy sand to clay loam material formed by the breakdown of rock fragments because of blasting during mining. Similar mixtures of fragments are oriented in diagonal bands in old spoils because of the method used in building these platforms. Horizontal bands of lithologically similar materials 20 cm thick are common in new spoils where scrapers were used in regrading the spoils (1971-11, 1977-13; Appendix A). New spoils regraded with bulldozers or draglines have a uniform mixture of fragments throughout their depth (1970-15 Appendix A). Weathering and soil formation has modified the mixture of parent materials in 50-year-old spoils. Thin A horizons have formed, and weakly consolidated rock fragments have disintegrated into soil. The mixing and breaking down of fragments indicates that cambic B horizons are beginning to form in minesoils .

Table 4. Composition of minesoils (%) based on 3 point counts (of 100 counts each) at 50 cm depth. Several different types of rock fragments occur in minesoils .

		Rock Fragments (%)					
SITE	Unconsolidated Matrix (%)	Soft Sandstone	Silty Shale	Hard Sandstone	Porcelanite	Coal	Al Horizon Fragments
1928-5	45.6	39.9		2.1			11.7
1927-7	65.9	21.5		0.3			12.2
1928-9	57.4	34.3		6.1			1.3
1929-10	63.2	3.1	27.1		6.6		
1948-3	59.4		32.1			8.5	
1969-14	51.0		28.2	2.0		18.9	
1970-15	83.8	6.8	4.9		4.2	0.3	
1972-13	66.9		4.5	25.1	3.4		
1973-12	65.0	13.2	12.5		2.0	7.3	
1975-11	61.4		38.6				

Carbon and Nitrogen Profiles

Figure 13 shows the range in organic carbon content with depth in native soils; old, and new spoils. Native soils contain more organic carbon than spoils between 10 and 100 cm. Old spoils, however generally contain more organic carbon above 10 cm and below 100 cm. Litter builds up quickly in the highly-productive pioneer community on old spoils causing a rapid increase in soil organic matter in the upper 1 to 2 cm. Mixing of pre-existing A horizons into old spoils during deposition may have caused the increased organic carbon levels below 100 cm. New spoils also show an increase in organic carbon in the upper 5 cm. This may be due in part to application of "topsoil"

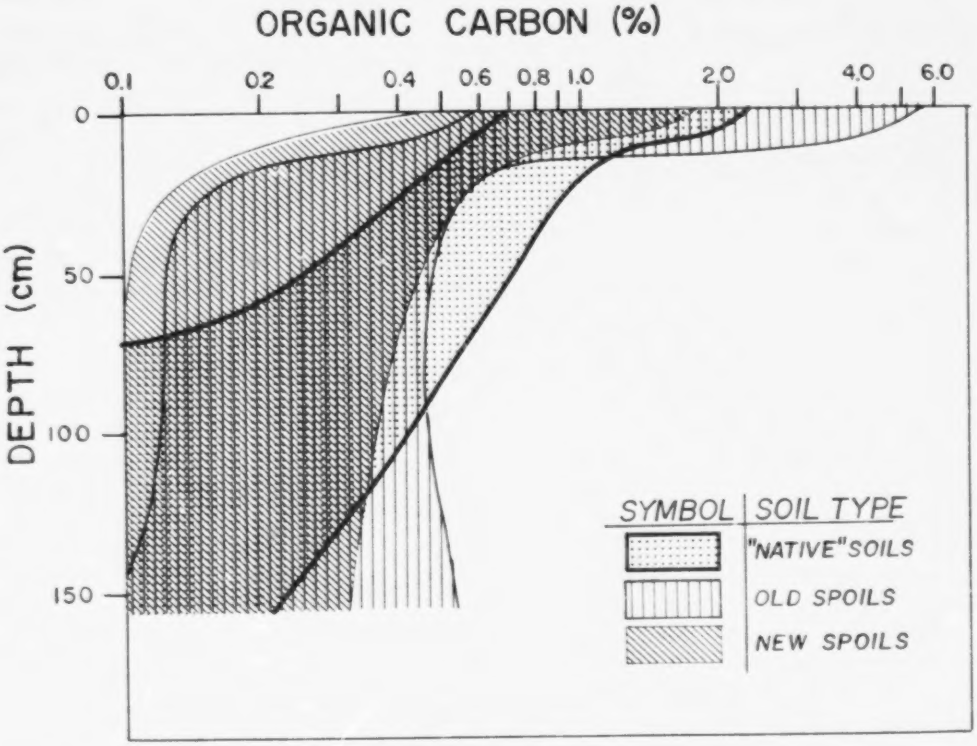


Fig. 13. Range in organic carbon content of natural soils and mine soils.

derived from surface horizons of pre-mine soils. Old spoils contain more organic carbon at all depths than do new spoils. This increase results from decomposition of grass and shrub roots over the 50 year period since deposition of old spoils. Organic carbon accumulates rapidly in the top 1 cm of spoils to equilibrium levels after 50 years (Table 5). Accumulation is much slower below 10 cm; 200 to 400 years may be required for organic carbon to reach a steady state level (Fig. 14). Dahlman and Kucera (1965) found a similar pattern in Missouri tall-grass prairie; 110 years were required to reach organic matter equilibrium in the upper 25 cm compared to 590 years for the 50-75 cm zone.

Table 5. Organic carbon accumulated at various depths in soils at Colstrip. Natural soils have less carbon in litter and a smaller C/N ratio than minesoils .

	Organic carbon accumulation				Fraction of OC in litter	C/N
	0-1 cm	2-5 cm	10-20 cm	0-100 cm		
Natural soil	.321	.435	.92	5.43	1	10
Old mine soil	.363	.243	.11	1.47	23	17
New mine soils	.208	.033	.00	.58	29	16

Anderson (1977) found rates of carbon addition to glacial-till minesoils in Saskatchewan (28.2 g m^{-2} yr^{-1}) similar to those in this study (25.6 g m^{-2} yr^{-1} Schafer and Nielsen, 1977). However, nitrogen accumulation was nearly twice as fast (2.43 g m^{-2} yr^{-1}, in Saskatchewan; 1.48 g m^{-2} yr^{-1} in this study). The disparity in carbon and nitrogen addition rates resulted in wide carbon/nitrogen ratios in minesoils in Colstrip compared to local natural soils. Wide C/N ratios may have resulted from the high production of pioneer plant communities coupled with a delay in litter decomposition. As a result, large amounts of litter accumulated on old spoils which tied up a large fraction of the total carbon and nitrogen in the ecosystem. Microbiological studies indicate nearly equal populations of heterotrophic organisms near the surface of minesoils and natural soils (Hersman, 1977). A large fraction of nitrogen in revegetated spoils may have been utilized by microorganisms in digesting the large carbon source in litter, making nitrogen less available for the plant community. Reeder and Berg (1977) found a similar lack of mineralized N after incubation of Cretaceous shales with wide C/N ratios. Lack of available (mineralized) nitrogen in spoils may be the cause of successional stagnation of some plant communities at a half-shrub/annual grass seral stage (1928-5). The old spoil resembling native range most in vegetative character (1929-10) has nearly twice as much total C and N in the system, with a smaller fraction of these elements immobilized in plant litter. Processes which prevent litter accumulation such as fire or grazing may be necessary to prevent immobilization of nitrogen and successional stagnation of plant communities. Intensive N fertilization of newer spoils delays but does not prevent litter accumulation and decreased production (DePuit and Coenenberg, 1978). Fertilization does reduce wide C/N ratios and promotes plant growth. Subsequent litter build-up causes stagnation of the plant community unless the site is harvested, grazed, or burned periodically.

Phosphorus Fractions

Samples from three pedons representative of old spoils, new spoils and natural soils were selected for fractionation of phosphorus. Total P was measured as well as several different forms of inorganic P. Organic P was

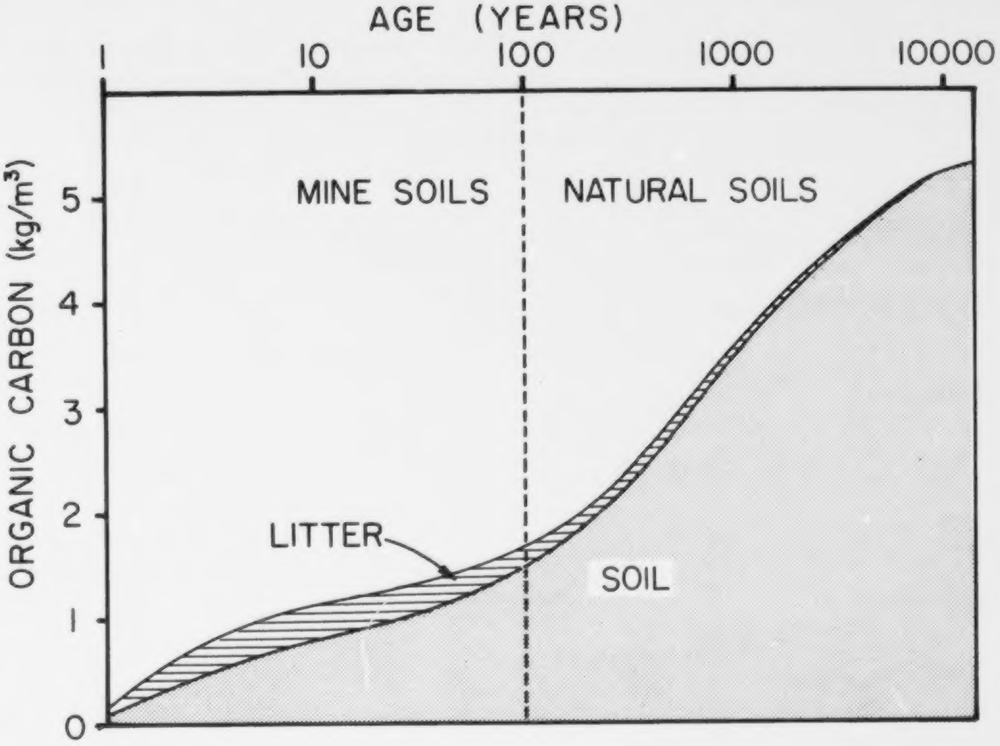


Fig. 14. Organic carbon accumulation through time showing fraction in litter.

calculated as the difference between total P and the sum of inorganic P fractions (Table 6).

Aluminum-and iron-phosphates as well as occluded aluminum phosphate, and reductant-soluble phosphate each comprised a small fraction of the soil phosphorus. Few differences existed between soils in the magnitude of each fraction. The relative amount of iron- and aluminum-phosphate, and occluded aluminum phosphate was greater in the upper 1 cm of each soil. A reduction in pH at the surface along with carbonate removal may have caused a transformation of soil P into these fractions. Calcium phosphate is the dominant inorganic form of P in all soils. Organic P also comprises a large component of total P in these soils. However, organic P does not decrease with depth as does organic matter content. The organic P fraction which was calculated by difference may, therefore, also include a component of insoluble inorganic P not affected by the extraction process.

The dominant form of phosphorus in nearly all unweathered parent materials is a calcium phosphate, apatite ($Ca_5(F, Cl, OH)(PO_4)_3$). During the soil development process, calcium phosphate is often converted to iron- and aluminum-phosphates; and organic phosphorus. Therefore, a comparison of the amounts of soil phosphorus in each fraction provides an index of soil maturity

(Walker and Syers, 1976).

Table 6. Fractions of inorganic and organic phosphorus in a typical old minesoil , natural soil, and new minesoil (Chang and Jackson, 1957).

P-Fractionation*

Site	Depth (cm)	Al -P	Fe -P	Ca -P	Red -P	Oc-Al-P	ORG-P	Tot -P	Free Fe%
		p-ppm							
Old Mine Soil (1928-9)	1-2	34	15	199	20	19	110	397	.18
	5	31	15	183	20	22	273	544	.17
	10	16	15	163	35	29	302	560	.13
	15	19	15	194	20	12	244	504	.14
	50	16	15	205	20	19	190	465	.18
	100	16	7	211	13	19	80	346	.03
	200	16	15	205	13	22	30	301	.10
Natural Soil (Chinook-8)	0-1	80	18	146	20	29	171	464	.20
	2	53	18	130	20	22	288	531	.19
	5	46	18	146	20	26	208	464	.17
	10	25	18	130	28	12	0	190	.23
	25	28	18	127	20	19	247	459	.23
	50	28	15	146	6	48	257	500	.09
	100	25	11	173	20	26	150	405	.27
	150	22	15	159	28	26	218	268	.22
	200	22	18	163	28	33	209	473	.12
New Mine Soil (1973-12)	0-1	80	34	194	20	36	194	558	.16
	2	46	11	173	20	29	198	477	.15
	5	16	15	183	20	22	266	522	.01
	10	25	15	183	20	12	177	432	.18
	50	14	7	173	20	19	240	473	.14
	80	16	11	154	35	19	220	455	.21
	100	16	15	194	20	19	182	446	.03
	200	14	15	159	20	5	125	338	.15

*Phosphorus fractions include aluminum phosphate, iron phosphate, calcium phosphate, reductant soluble phosphate, occluded aluminum phosphate, organic phosphorus, and total phosphorus.

Williams and Walker (1969a, 1969b) studied phosphorus transformations in a chronosequence of New Zealand soils. They found that calcium phosphate decreased rapidly to near zero in the soil development sequence. Apatite weathered from the profiles more rapidly than feldspar, hornblende, or volcanic glass. Although some P was removed from the profiles, most calcium phosphate was converted to secondary iron- and aluminum-phosphate; and with extreme maturity to occluded phosphate. Organic P reached a peak during intermediate stages of soil development. All soils in this study are genetically young soils when compared to the New Zealand chronosequence. Because of the semi-arid climate, the pH of Colstrip soils is high enough so calcium phosphate remains the primary inorganic form. The calcium-phosphate fraction of these soils may contain apatite, octa-calcium phosphate, and phosphorus, precipitated on calcium carbonate surfaces (Russell, 1973).

Syers and others (1969) studied two New Zealand alluvial soils radiocarbon dated at 650 and 6500 years B.P. The youngest soil had an organic phosphorus distribution similar to that found in this study. Organic P did not decrease with depth as did organic matter content. Organic P as well as secondary inorganic phosphorus were more concentrated in the fine particle-size separates of the New Zealand soils. Primary apatite-phosphorus was most abundant in the fine sand fraction.

John and Gardner (1971) found a decrease in calcium phosphate with increasing soil age in Canadian alluvial soils. A parallel increase in iron- and aluminum-P and organic-P was also noted. The amount of calcium phosphate was highly correlated with the Bray-2 soil test for phosphorus (Bray and Kurtz, 1945).

Calcium phosphates are relatively unavailable at the pH found in these soils. The dominant phosphorus-containing species are probably octa-calcium phosphate and apatite which provide very little P to solution (Russell, 1973). As a result, most minesoils in the region are considered deficient in phosphorus (Power and others, 1978). Bowman and Cole (1978) stress the importance of organic P as a plant-available phosphorus source in western soils.

Mobile Soil Components

Soluble salts: Electrical conductivity (EC) of all soils in the Colstrip area is low (usually <1 mmho/cm). Values as high as 4 mmhos/cm were found near the surface of new spoils and below 100 cm in native soils, however. Between 10 and 40 cm, natural soils have lower EC than old spoils, which in turn have lower EC than new spoils (Fig. 15).

The EC of some natural soils increases below 100 cm indicating that salts accumulate near the base of the root zone. Old spoils below 10 cm have uniform EC values between 0.2 and 0.4 mmhos/cm. The material was initially low in salts. Dollhopf and others (1978) found that the upper 5 to 10 m of overburden often is the most saline with EC greater than 4 mmhos/cm. Since old spoils were derived mostly from below ridges in the landscape, it is possible that overburden beneath these positions are free of salts in the upper 10 m. A similar pattern of salt distribution was found at several North Dakota mines by Moran and others (1978). Some new spoils approach 0.2 mmhos/cm between 10 and 100 cm but increase to 1.0 mmhos/cm below 100 cm. This salt distribution may result from the rapid leaching of salts to the base of the root zone. Anderson (1977) found that salts in minesoils were removed from the upper 50 to 100 cm after 30 years. This finding contradicts the suggestion of Curry (1975) that disruption of the Northern Great Plains ecosystem by mining would cause salts to move upward and accumulate at the surface of minesoils .

Soluble salts in natural soils consisted of nearly equal amounts of Ca^{++} and Mg^{++} with small amounts of Na^{+} and K^{+} (Appendix A). The dominant anions were HCO_3^- and SO_4^{-2}. Below 100 cm in natural soils, EC was higher than in

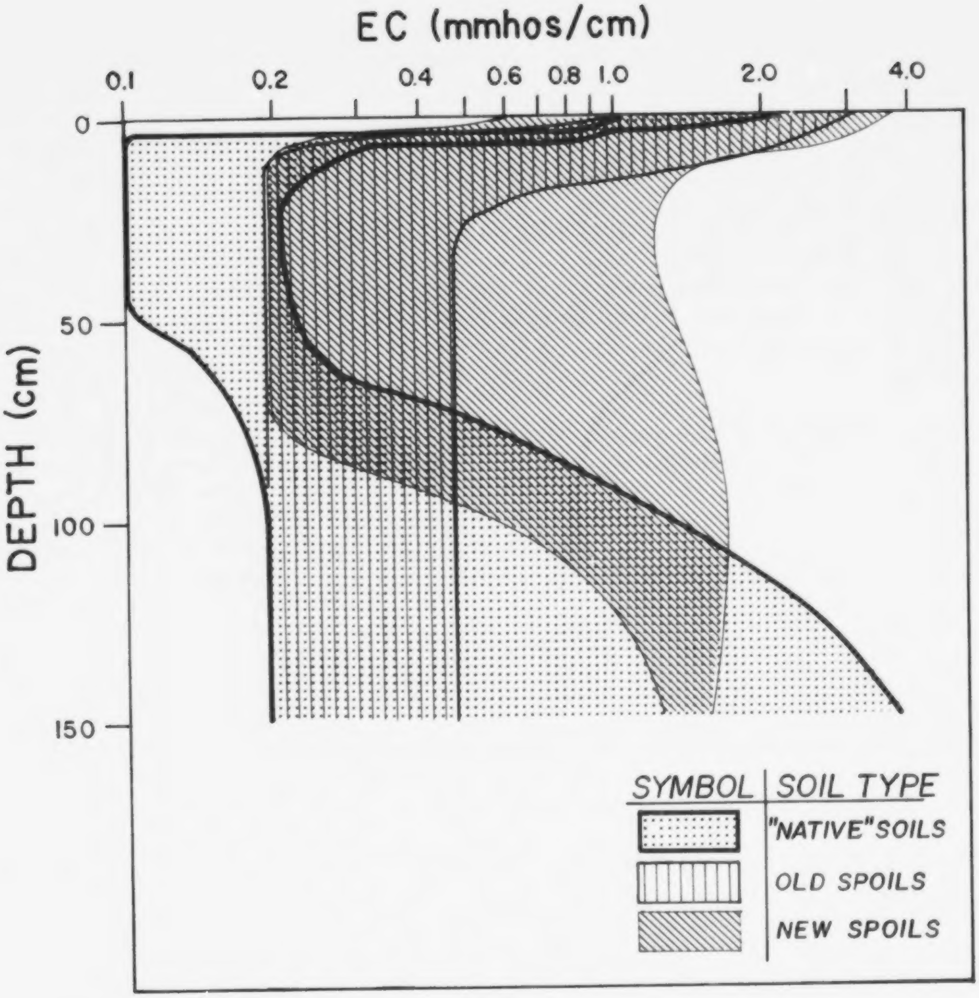


Fig. 15. Range in electrical conductivity in natural soils and mine soils.

the upper part of the profile. In addition, Mg^{++} and Na^{+} increased in relative abundance at this depth.

In old minesoils , Ca^{++} was two to four times more abundant than Mg^{++}. The dominant anion was HCO_3^-, but SO_4^{-2}, and Cl^- were more abundant in old spoils than in natural soils.

In new minesoils , Mg^{++} and Na^{+} were more abundant than Ca^{++}. Excess

Mg^{++} could compete with uptake of sufficient Ca^{++} for plant growth despite the calcareous nature of new spoils (Power and others, 1978). Sulfate is the dominant anion in new spoils, unlike natural soils and old minesoils where HCO_3^- is dominant. The different composition of salts in new spoils may be caused by 1) its source within an aquifer with dominantly Mg-SO_4 type water (Dollhopf and others, 1978b), or 2) weathering of pyrite and other minerals not found in old spoils or natural soils.

All soils studied showed a marked increase in EC in the upper 1 to 2 cm of the profile. This accumulation of salts could result from 1) evaporation of water from the soil surface leaving a residue of salts, or 2) "base pumping" or nutrient cycling of ions through the plant community. An evaporative salt residue should be composed of a large fraction of mobile ions such as Na^+, Cl^-, and NO_3^-. Salts derived from nutrient cycling should be rich in ions selectively accumulated by plants (such as K^+). A comparison of the ionic composition of soluble salts from different depths (Table 7) reveals that K^+ is higher in relative abundance near the soil surface than it is deeper in the profile. Nutrient cycling is, therefore, occurring in all but the most recent minesoils which concurs with the suggestion of Anderson (1977).

$\underline{CaCO_3}$: Fort Union sandstones are highly calcareous. Widmayer (1977) found that sandstones in the Decker area contained 13% $CaCO_3$ mostly as discrete carbonate sand grains. In this study, soils or soil parent materials contained 8 to 14% $CaCO_3$ both as sand-sized clasts and finer matrix and cement.

The carbonate distribution in natural soils indicates that $CaCO_3$ has been removed from the upper 30 to 50 cm of the profile and has accumulated below that depth (Fig. 16). Spoils show a uniform $CaCO_3$ distribution throughout the profile except in the upper 5 cm. Some old spoils have been somewhat leached in the upper 1 cm which represents the first stages of the formation of a carbonate distribution similar to natural soils. New spoils exhibit a decrease in $CaCO_3$ content only where non-calcareous "topsoil" has been applied. The practice of adding "topsoil" mimics several hundred years of soil genesis in terms of carbonate removal.

Calcium carbonate is a moderately mobile component in soils. In semiarid and arid regions $CaCO_3$ accumulates at various depths in the soil. Arkley (1963) developed a method for calculating the time required to form horizons of $CaCO_3$ enrichment based on climatic data, carbonate solubility, and soil properties. Using this method, the time required for carbonate removal to occur in natural soils at Colstrip was calculated (Table 8).

Variations in the age of soils can best be explained by relative landscape positions. The Boxwell-2 soil occurs under an upland relict surface of perhaps early Wisconsin age. All other soils lie below a late Wisconsin surface. Steepest slopes along interfluves on the younger surface are being eroded most rapidly and therefore exhibit minimum ages. The Chinook-1 soil is underlain by a buried soil at 1 m and suggests recent slope activity. The calculated age of this soil may be too high because the original $CaCO_3$ content may have been overestimated.

Table 7. Partial ionic composition of a saturation extract is shown from two depths for each soil. Plant nutrients such as K^+ are concentrated in surface horizons which indicates nutrient cycling has caused the surface salt accumulation observed in these soils.

		EXTRACTABLE CATIONS meq/1					% OF ION COMPOSITION			
SITE	DEPTH (cm)	Ca*	Mg	Na	K	TOT	Ca*	Mg	Na	K
CHINOOK-1	0-10	-	TR	TR	.5	.5	-	0	0	100
	100-200	-	24.7	.1	.4	25.2	-	98	0	2
BOXWELL-2	0-1	11.5	7.3	.1	2.3	21.2	54	34	1	11
	100-145	.6	2.1	1.0	.1	3.8	16	55	26	3
ETHRIDGE-4	0-1	12.9	11.9	.2	2.9	27.9	46	43	1	10
	100-152	1.1	10.2	16.0	.2	27.5	4	37	58	1
CHINOOK-8	0-1	-	2.2	TR	.5	2.7	-	81	0	19
	150-200	-	6.3	.1	.2	6.6	-	95	2	3
1928-5	0-1	-	4.1	TR	1.2	5.3	-	77	0	23
	100-200	-	4.8	0	.3	5.1	-	94	0	6
1928-7	0-1	-	2.8	TR	.7	3.5	-	80	0	20
	100-200	-	8.2	TR	.3	8.5	-	96	0	4
1929-10	0-1	-	4.2	TR	1.3	5.5	-	76	0	23
	100-200	-	9.5	.1	.2	9.8	-	97	1	2
1948-3	0-1	-	8.2	TR	1.2	9.4	-	87	0	13
	100-153	-	19.4	.1	.2	19.7	-	98	1	1
1975-11	0-1	4.8	1.9	.2	.4	7.3	66	26	3	5
	100-200	8.5	8.6	.5	.4	18.0	47	48	3	2
1973-12	0-1	-	4.7	TR	.7	5.4	-	87	0	13
	100-200	-	3.7	TR	.1	3.8	-	97	0	3
1972-13	0-1	-	5.8	TR	1.1	6.9	-	84	0	16
	100-200	-	2.9	TR	TR	2.9	-	100	0	0
1969-14	0-1	-	5.4	TR	.6	6.0	-	90	0	10
	100-200	-	4.3	TR	.1	4.4	-	98	0	2
1970-15	0-1	-	2.7	TR	1.3	4.0	-	68	0	32
	100-200	-	5.4	TR	TR	5.4	-	100	0	0

*Ca^{+2} was not measured in calcareous soils because of analytical difficulties. When Ca^{+2} values were missing, ion composition was calculated using only the remaining cations.

Based on Arkley's method (1963), carbonate should have been removed from the upper 2 cm of old spoils during a 50 year period. Although at least one old spoil (1929-10) is free of carbonate in the upper 1 cm, most old spoils are calcareous throughout the profile. Lab data and thin section evidence suggests that carbonate is being gradually removed from the upper 10 or 20 cm rather than being completely leached initially from the upper one or two cm. It is possible that the large grain size of original carbonates prevents the $CaCO_3$ from entering solution rapidly enough to be quickly removed near the surface. Instead, downward-moving precipitation dissolves minute amounts of carbonate from successively deeper depths until water finally becomes

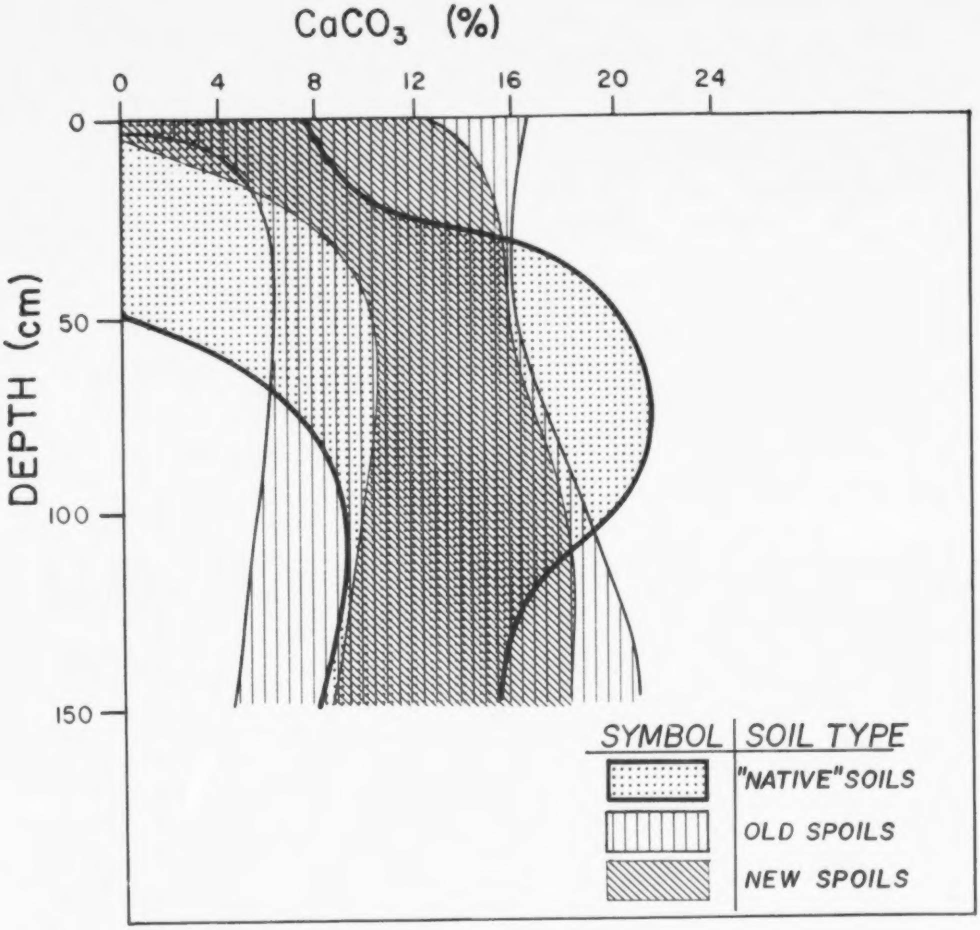


Fig. 16. Range in calcium carbonate content in natural soils and mine soils.

saturated with $CaCO_3$ at 20 to 50 cm. As water is later withdrawn from the soil by plant roots and evaporation, carbonates reprecipitate at the point where the water was removed (Fig. 17). This process continuing over several thousand years results in the carbonate distribution observed in natural soils.

Salomons and Mook (1976) used isotope geochemistry to study carbonate movement in Dutch polders. They verified the process of dissolution and partial reprecipitation outlined above. In the Dutch soils, about 20 percent of the carbonate dissolved in surface horizons was reprecipitated deep in the profile either as a result of evaporation or decrease in the partial pressure of CO_2. In the more arid environment of southeastern Montana, a much larger fraction of $CaCO_3$ (approaching 100 percent) would be expected to reprecipitate. Reprecipitated carbonates should have a very fine particle size because

Table 8. Years required for carbonate removal to occur in five soils near Colstrip. (These dates may vary considerably depending on how $CaCO_3$ solubility is calculated but should represent minimum estimates. Climatic data from central South Dakota was used in the calculation, based on the method of Arkley, 1963).

Soil	Minimum age (years)	Landscape position	Relative age
Chinook-1	4000	interfluve footslope	recent
Riedel-6	5200	interfluve backslope	recent
Ethridge-4	9300	middle backslope	late Wisconsin
Chinook-8	11400	footslope	late Wisconsin
Boxwell-2	32500	slope summit	late Wisconsin

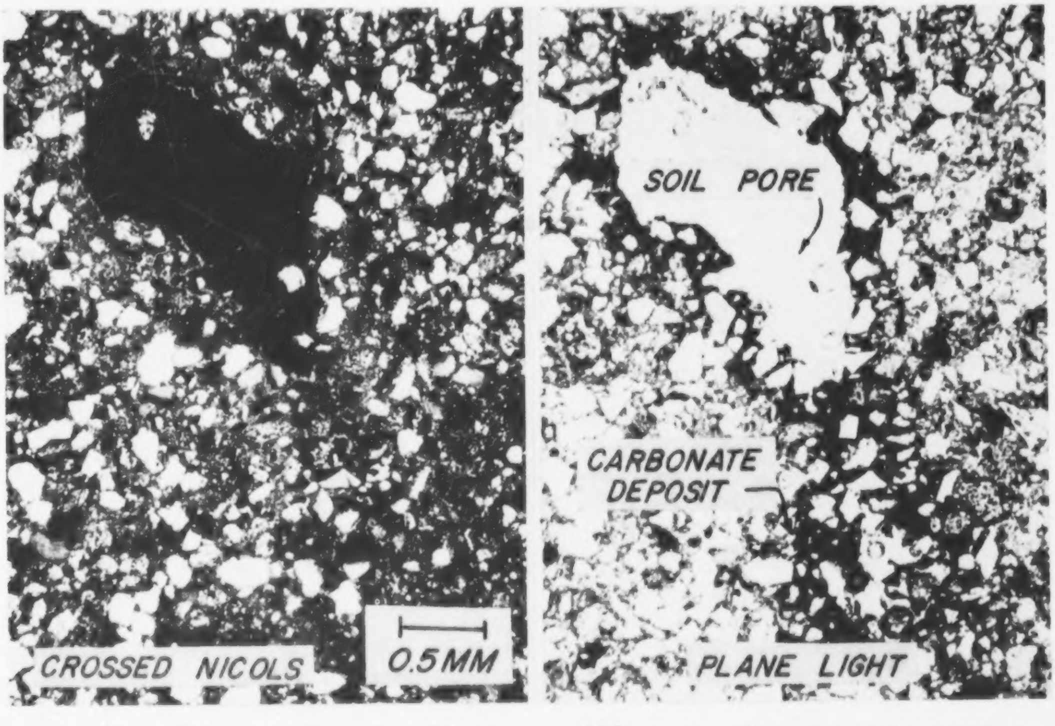


Fig. 17. Thin section of soil pore at 100 cm in old minesoil showing carbonate enrichment.

of their rapid formation (Fig. 18). Old minesoils have a significant amount of clay-sized carbonate similar to C_{ca} horizons of natural soils (determined by X-ray diffraction). New minesoils have very little clay-sized carbonate.

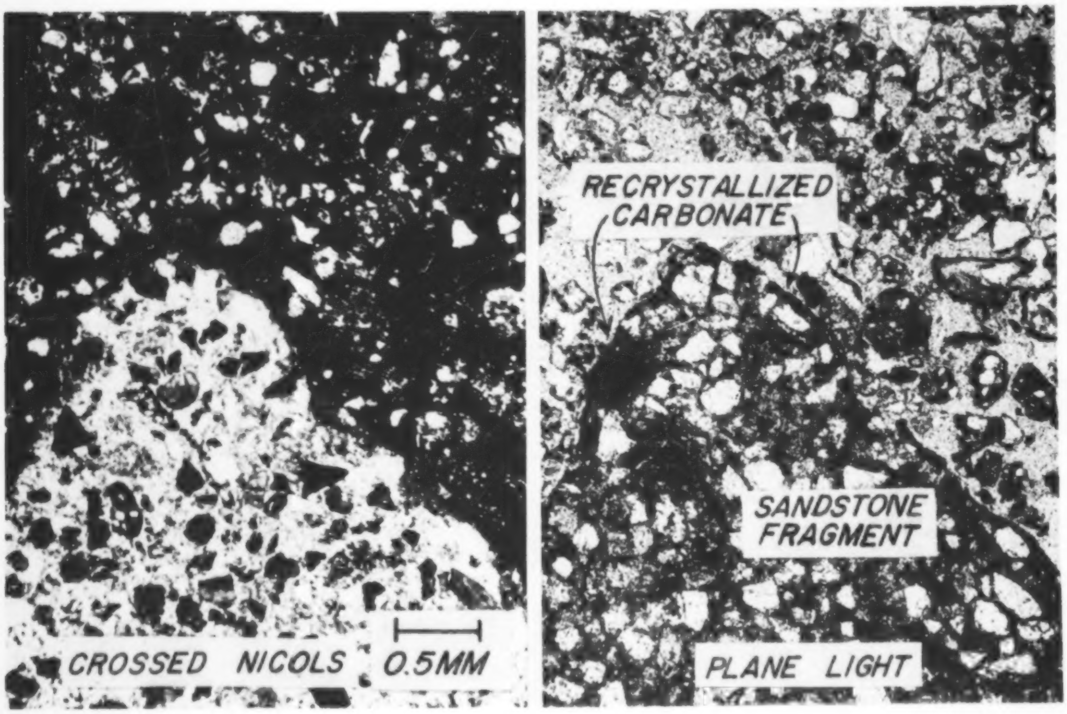


Fig. 18. Thin section of sandstone fragment (lower portion of photo) in old minesoil . Fragment has large $CaCO_3$ crystals in interior but small recrystallized $CaCO_3$ around rim.

Dissolution of sand-sized carbonate grains may also play a major role in the breakdown of sandstone rock fragments in old minesoils .

pH: The pH of calcareous soils is usually controlled by the solubility of calcium carbonate, carbonate equilibria, and the CO_2 pressure. With normal CO_2 partial pressure ($pCO_2 = 10^{-3.5}$ Atm) and pure calcium carbonate, pH approaches 8.4 in aqueous systems (Garrels and Christ, 1965). The presence of other soluble salts or ions such as Na^+, or $CaSO_4$ can raise or lower the equilibrium pH. Organic acids in A horizons also tend to lower pH.

The pH of most samples from Colstrip was near 8.3 reflecting the high $CaCO_3$ content and lack of Na^+ or other soluble salts (Fig. 19). Leaching of carbonates and formation of organic acids in natural soils has resulted in a lower pH (6.5-8.0) in the upper 50 cm. Old minesoils show a smaller reduction in pH in the top 30 cm as a result of soil development processes. New spoils are generally uniform in pH throughout their depths except where "topsoil" from the A horizon of pre-mine soils were added.

Trace Elements

Extractable levels of seven trace elements; Fe, Mn, Zn, Cu, Ni, Pb, and Cd were measured in three soils using a DTPA extraction (Soltanpour and

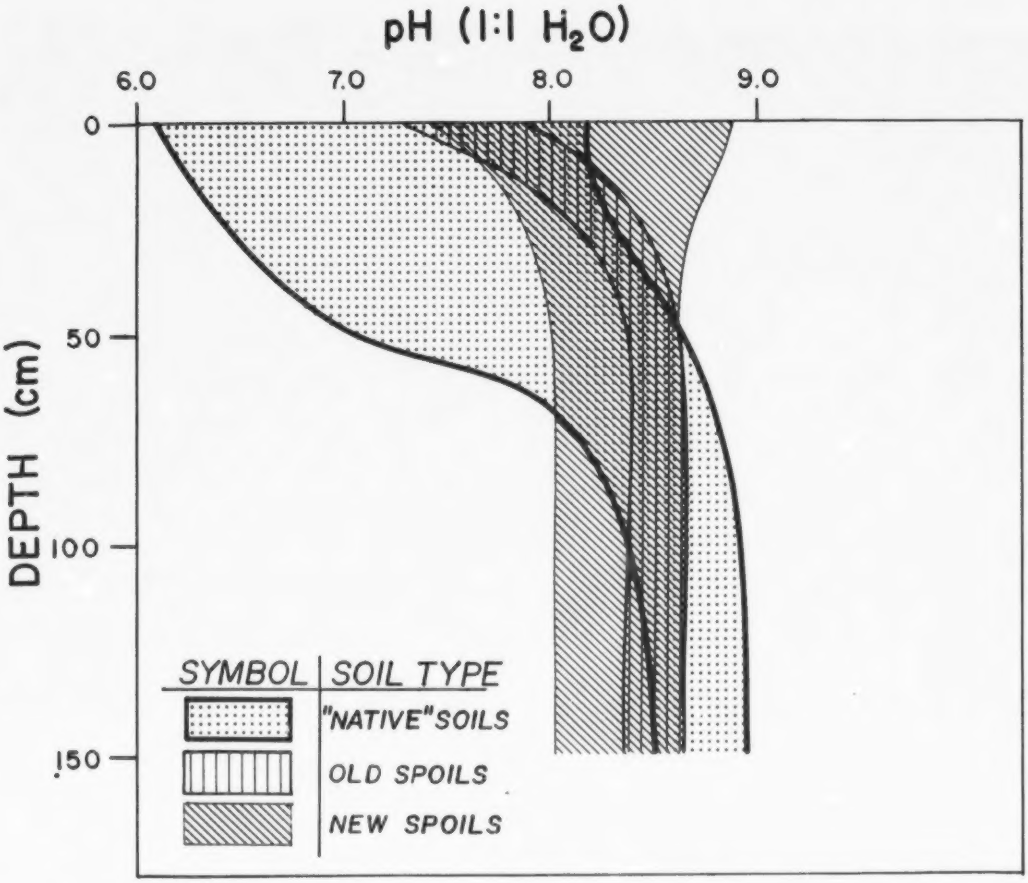


Fig. 19. Range in pH for natural soils and minesoils.

others, 1976; Follett and Lindsay, 1971). Extractable trace element levels have been used to determine potential phytotoxicity in stripmine spoils (MDSL, 1977). Gough and others (1978) found that DTPA, EDTA, and ammonium oxalate soil extractions did not predict more than 50% of the variability in elemental concentration of range plants growing on selected soils in the Northern Great Plains. These methods were of limited utility in predicting plant availability. They were useful, however, in defining general ranges in concentration which were suitable for plant growth media.

Zinc: Follett and Lindsay (1970) found that available Zn increased with an increase in organic matter or cation exchange capacity in Colorado soils. Less than 0.5 ppm extractable Zn was considered low for crop production. The distribution of Zn in old, and new spoils; and natural soils is shown in Fig. 20. Extractable Zn increases near the surface of all soils perhaps due to nutrient cycling and complexing with organic matter in surface horizons.

Natural soils and old minesoils were near the lower limit of adequate plant available Zn below 10 cm. Zinc deficiency may be a problem in these

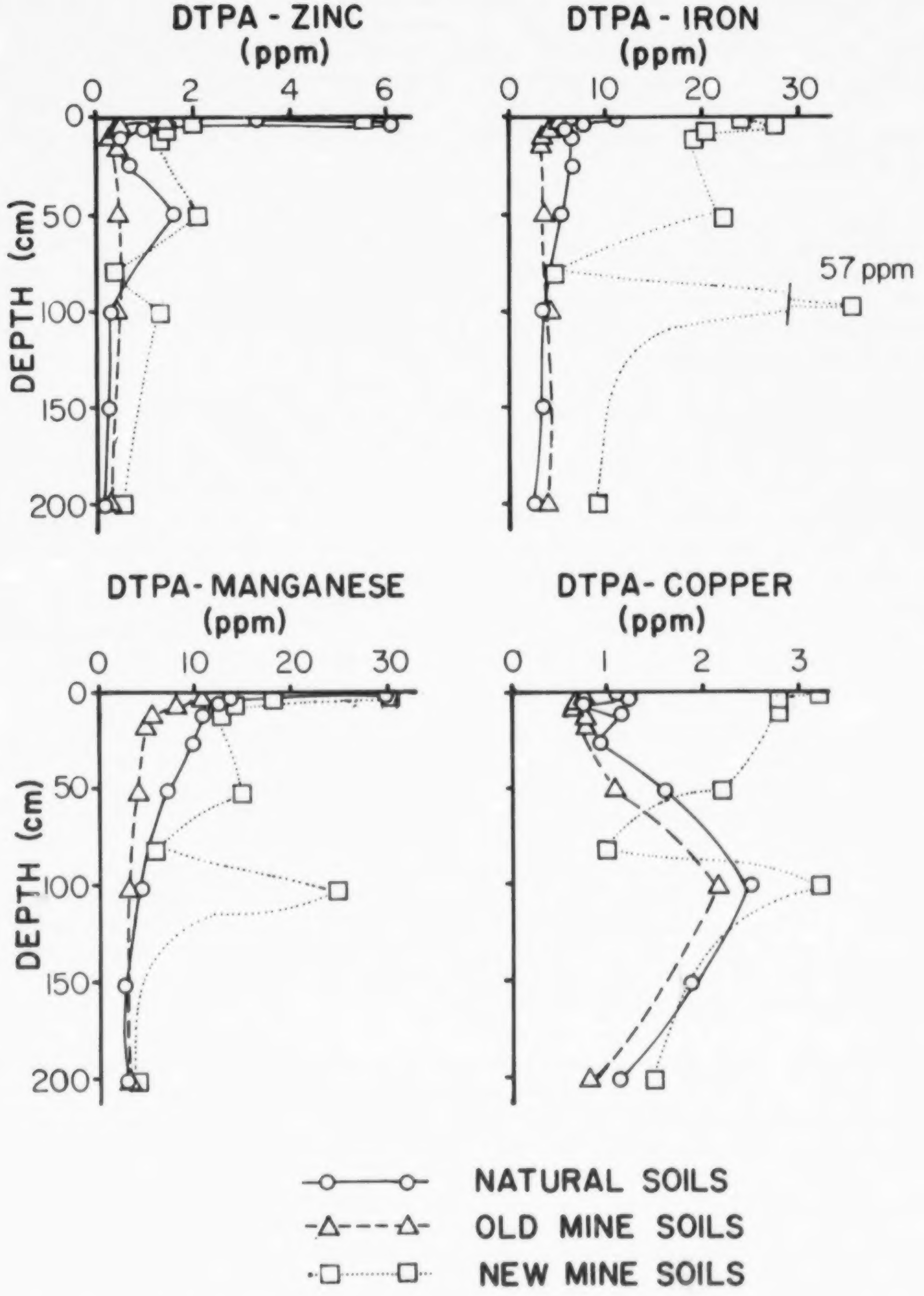


Fig. 20. Distribution of DTPA-extractable Zn, Fe, Mn, and Cu in natural soils and minesoils.

soils especially late in summer when surface horizons are dry thus slowing ion uptake from the zone where Zn is concentrated. Munshower and Neuman (1978) found that several range grasses growing on unmined soils near Colstrip had Zn concentrations below the dietary requirement for cattle forage. Zinc concentration in grasses decreased from spring through fall. Safaya (1978) found a slight response to Zn on North Dakota minesoils when adequate N and P were added.

Iron: Extractable iron generally increases with decreasing pH. Iron distribution in old minesoils and natural soils are nearly uniform with depth which may be due in part to the nearly constant pH of these soils with depth (Fig. 20). Iron concentration is near the lower limit suggested by Follett and Lindsay (1970). Iron deficiency may also occur on these soils since free lime is abundant at most depths.

The distribution of iron in new spoils is not explained by pH differences. Iron content is much higher than in other soils. The large increase in extractable iron at 100 cm corresponds to a layer of silty material texturally distinct from other horizons. This layer may have been derived from material below the water table where low redox potential caused ferrous (Fe^{+2}) iron to be the dominant form. Ferrous iron is much more soluble than the ferric (Fe^{+3}) form which would account for the elevated concentration. Ferrous iron tends to oxidize to the ferric form and precipitate as iron oxides when in contact with the atmosphere. Bands of iron oxide paralleling the silty layer (Fig. 21) suggest that diffusion of ferrous iron and oxidation does occur in new minesoils .

Manganese: Available Mn tends to increase with organic matter and decrease with increasing soil pH and lime content. Manganese content of old spoils and natural soils tends to increase near the surface as does Zn (Fig. 20). Adequate Mn for plant growth is indicated, however.

Manganese like Fe is also strongly affected by changes in the redox potential (Ponnamperuna, 1972). Manganese concentration shows a large increase in the silty layer at 80-100 cm in new spoils much like iron. A thin section of a siltstone fragment shows precipitation of opaque MnO_2 along fractures indicating that reduced Mn is oxidized when in contact with the soil atmosphere (Fig. 22).

Copper: Available Cu increases with increasing clay content and total Cu in soils. As a result, Cu concentration decreases near the soil surface unlike Zn and Mn. Decreased Cu content near the surface of old spoils and natural soils may be due to organic matter - copper complexes which make Cu less available to plants (Fig. 20).

Copper content of new spoils has an erratic distribution with depth. Copper availability may be more influenced by differences in Cu content of parent materials, than by other soil properties like organic matter, or clay content.

Lead: Lead content of all soils increased slightly near the surface similar to Zn and Mn (Fig. 23). New minesoils had an erratic Pb distribution.

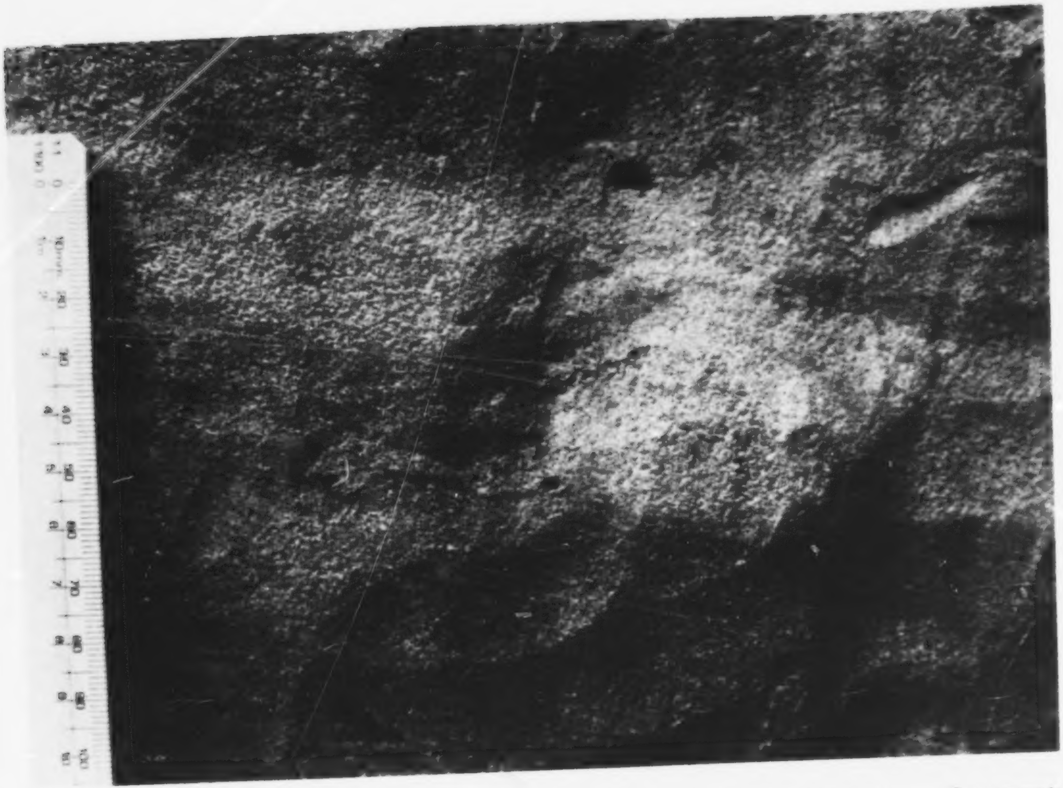


Fig. 21. Bands of iron staining parallel the low chroma sandstone fragment in the center of the picture.

Nickel: The distribution of nickel was similar to lead in most soils (Fig. 23).

Cadmium: Cadmium content was uniform with depth in minesoils (Fig. 23). Cadmium content increased near the surface in natural soils. New spoils were slightly higher in extractable Cd than old spoils or natural soils.

The distribution of extractable Zn, Fe, Mn, Cu, Pb, Ni, and Cd in old minesoils was similar to natural soils. The variation in element concentration with depth in old spoils and natural soils could be explained by the effects of pH, and organic matter on element availability. The extractable elemental content of new spoils was more closely related to the nature of the parent material. The previous location of material comprising new spoils may be a factor explaining the variability of element distribution of these soils. A silty layer which perhaps was derived from an aquifer had highest levels of nearly all trace elements examined. The reduced form of many elements, especially Mn and Fe, are more mobile than the oxidized form. Differences in mobility, and the rate of oxidation of reduced ions may have an important influence on phytotoxicity and ground water quality in mined land. If it is assumed that old spoils were initially variable in trace element concentration, like new spoils are now, then less than 50, but more than 3

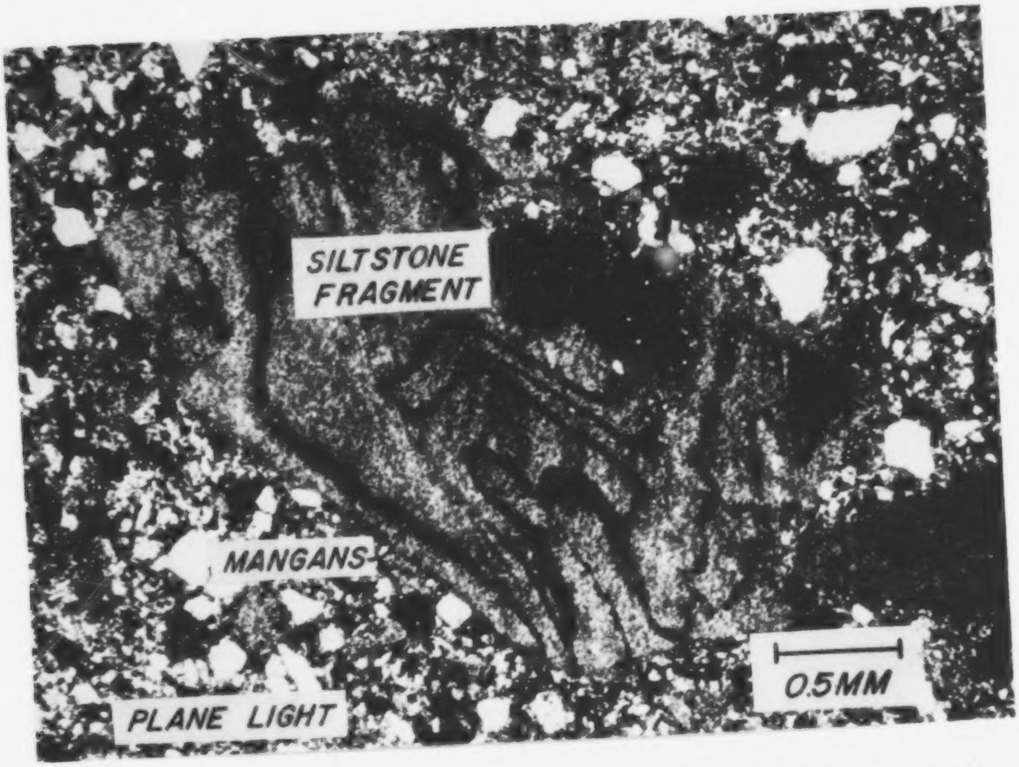


Fig. 22. Thin section of siltstone fragment showing manganese bands (mangans) paralleling fractures.

years are required for the trace element distribution to resemble that of natural soils.

Other evidence of transformations of trace elements was found in mine soils which contained coal fragments. Many coal fragments were surrounded by a prominent concentric layer of iron-stained soil 2 cm thick (Fig. 24). The pH of affected coal fragments was 2.1, the interior of the iron-stained layer was 2.5, the outside of the layer was 6.0, while the spoil matrix was 8.3 (Table A-28). Banding only developed around coal fragments which contained pyrite. Apparently the pyrite is attacked by Thiobaccilus ferroxidans, a microorganism which gains energy through oxidation of the iron and sulfur in pyrite (Temple and Colmer, 1951, Temple and Delchamps, 1953). One of the by-products of this process is H_2SO_4 which dissociates to cause the low pH. Because of the large amount of $CaCO_3$ in these minesoils, and the small amount of pyrite, only a small volume of soil is affected by the low pH. It appears that the first product of pyrite breakdown is a ferrous sulfate complex, because the iron is mobile enough to diffuse away from the pyrite. Finally, the ferrous iron is oxidized to the ferric form which precipitates in the distinctive red bands, paralleling the coal fragment. The sulfate produced by this process combines with calcium to form gypsum crystals replacing the pyrite. From examination of the iron staining in this section it appears

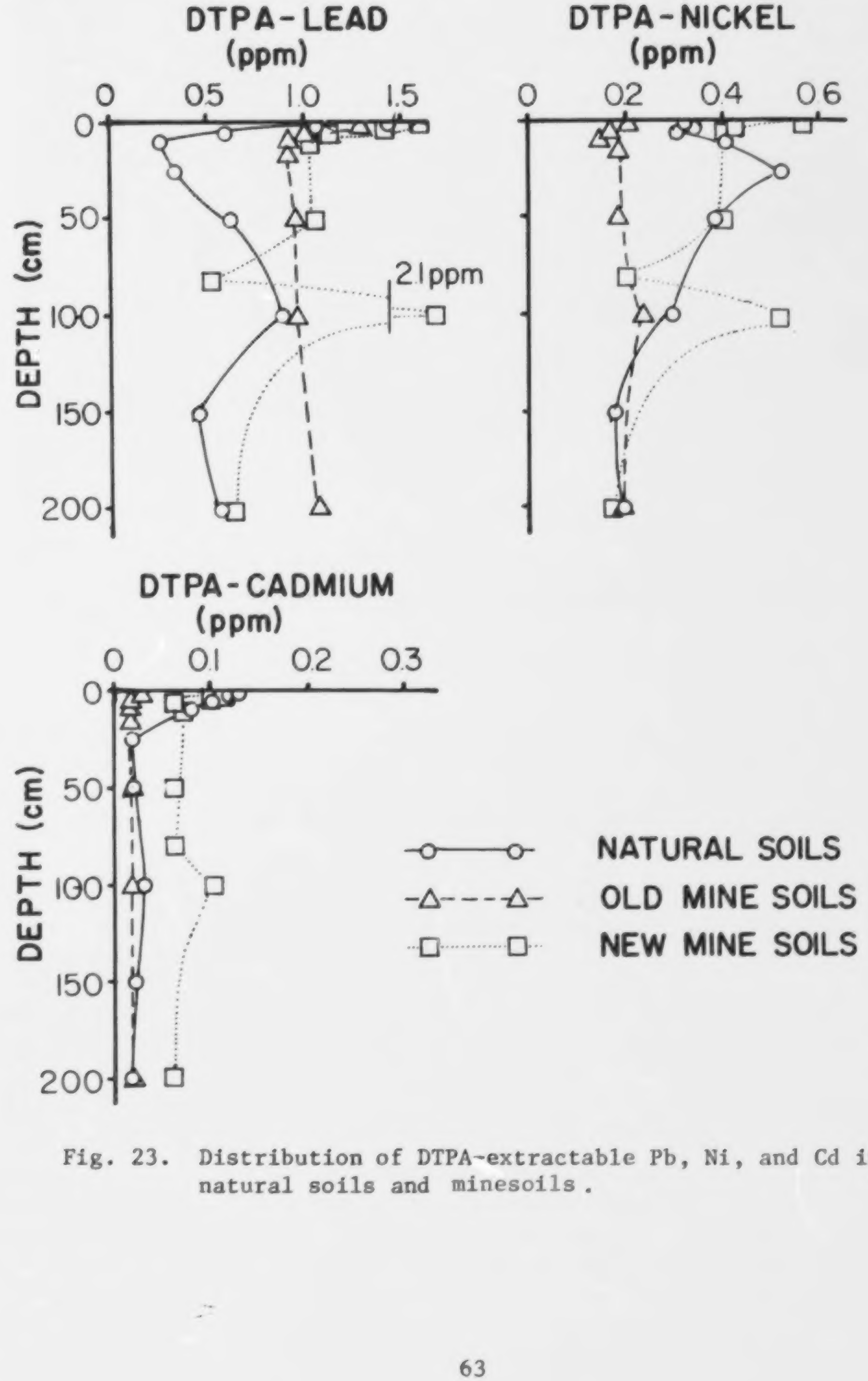


Fig. 23. Distribution of DTPA-extractable Pb, Ni, and Cd in natural soils and minesoils .

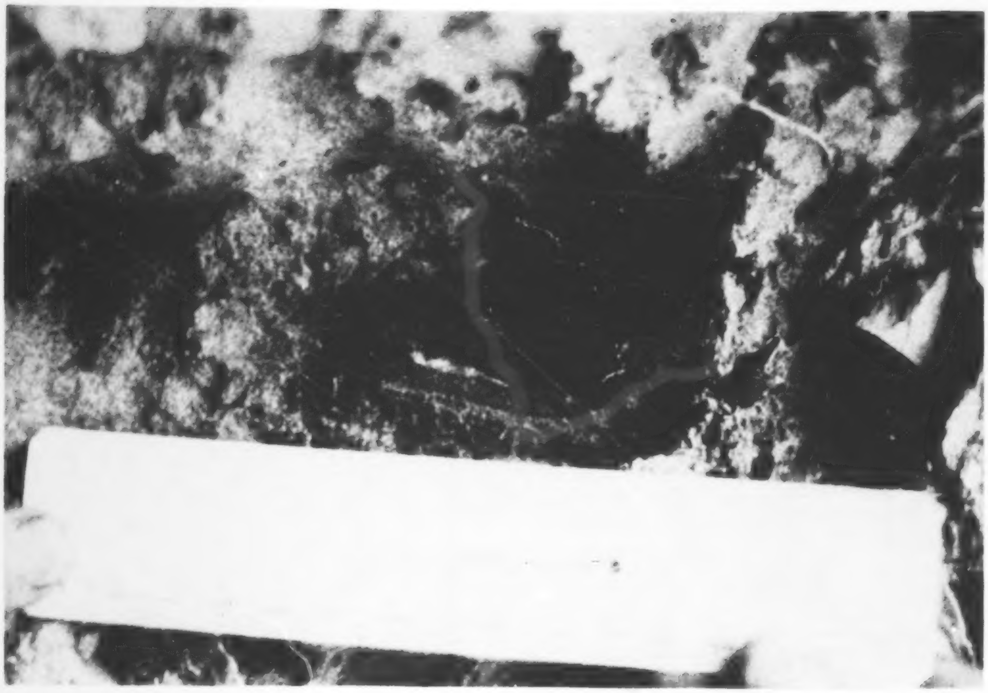


Fig. 24. Coal fragment showing bands of iron-staining paralleling fragment. White material around coal is gypsum.

that the iron-stained area is made up of several distinct bands. The number of bands roughly corresponds to the number of years the coal fragment has been exposed to weathering. Thus, one band may be produced each year, for example in late spring when the soil is wet and warm enough for biological activity.

The process of iron-band formation around coal fragments is similar to many transformations involving trace elements in minesoils. The mining process can intimately mix materials from different segments of the overburden. As a result, the elemental content of the minesoil is often initially quite variable on a micro-scale (< 10 cm). Iron and manganese have been observed to diffuse away from zones of localized concentration (Figs. 22 and 24). This diffusion process acting through time should tend to homogenize the distribution of some trace elements. This process of homogenization is unlike processes which have been observed in natural soils. In fact, the opposite process often occurs. Natural soils are usually homogenous in Mn and Fe content initially. Extreme weathering or periodic changes in redox often cause localized concentrations or concretions of Fe and Mn to form. Thus the unique origin of minesoils has resulted in unique processes of soil development at least in the case of iron and manganese movement.

Clay Mineralogy

The abundance of individual clay mineral species of selected horizons was determined semi-quantitatively by x-ray diffraction methods. The three groups of soils; old spoils, new spoils, and natural soils represent three distinct mineralogic regimes. Natural soils formed in the top two meters of geologic material and have been exposed to weathering for several thousand years. Old spoils were derived from the upper 8 m of overburden, thus have undergone less severe weathering. New spoils originated from materials throughout the overburden perhaps with most material from just above the coal seam. As a result of these different origins of material, three distinct suites of clay minerals have resulted in these soils.

The clay fractions of three groups of soils had nearly equal proportions of mica, smectite, and quartz (Table 9). The amount of kaolinite varied from only moderate in natural soils to dominant in new spoils. Kaolinite abundance increased as the depth from which the parent material was derived increased. In other words, kaolinite would be expected to increase with depth in the overburden. This agrees with the findings of Klages (1975) in his analysis of several overburden cores from the Decker, Montana area.

Table 9. Clay mineral abundance in the clay fraction of natural soils and minesoils at Colstrip, Montana (values reported are the mean from all horizons).

Clay mineral Species	Natural Soils	Old Mine Soils	New Mine Soils
Kaolinite	3*	4	5
Mica	2	2	2
Smectite	1	0	1
Quartz	1	1	1
Calcite	0	1	0
Chlorite	0	0	2
Smectite/Chlor.	1	2	0
Vermiculite	0	0	1

* 5	Dominant
4	Abundant
3	Moderate
2	Small
1	Trace
0	Not Detected

Clay-sized calcite is nearly absent in new minesoils . New minesoils lack clay-sized calcite despite an abundance of carbonate in the whole soil. Apparently the primary calcite grains are dominantly silt or sand-sized. Natural soils are free of clay-sized calcite in the upper 50 cm due to complete removal of calcite from these horizons. Old minesoils have a trace of clay-sized calcite which may indicate that much of the silt- and sand-sized carbonate has dissolved and reprecipitated in a 50-year period. Thin sections of old minesoils verifies this conclusion (Fig. 18).

Chlorite occurs in small amounts in new minesoils but not in other soils. A similar smectite-chlorite interstratified mineral occurs in small amounts in old minesoils . Removal of alternate brucite sheets from the chlorite in new minesoils could have given rise to the interstratified mineral in old spoils. However, for this change to occur in 50 years, the chlorite mineral would have to be very unstable in the chemical regime of these soils.

Fabric-Related Properties

Clay: Natural soils generally contain more clay than minesoils indicating a difference in parent material (Fig. 25). Old minesoils are sandy because they were derived from partly resistant sandstone knolls. New spoils are low in clay because of the dominance of silt and fine sand in the overburden, and the selective placement of sandy material in the upper two m of the soil.

The bulge in clay content at 80 to 100 cm in the new spoils corresponds to a stratification of clayey material deposited by a scraper in the 1975-11 pedon. Where scrapers are used to deposit minesoils, many abrupt changes in texture are observed. Abrupt textural changes have a strong influence on water and solute movement in soils. Sandy substrata can prevent percolation of water until surface horizons are saturated (Gardner, 1968). Clayey substrata may slow percolation and reduce infiltration rates. Abrupt changes in texture influence soil management enough to be recognized in soil classification (Soil Survey Staff, 1975). In addition clayey substrata can be strongly compacted if deposited when moderately wet. Severe compaction has been observed to prevent root penetration in many new mine soils. A restricted rooting depth results in less available water for plant growth during the critical mid-summer periods.

Clay is a mobile component in many soils. Removal of clay from the upper profile and accumulation in B horizons, results in the formation of an argillic horizon. An argillic horizon has formed in the Ethridge-4 soil between 10 and 31 cm. Evidence of clay movement exists in the Boxwell-2 pedon (Fig. 26), but not enough has moved to form an argillic horizon.

As a result of higher organic matter and clay content, natural soils have a much higher cation exchange capacity (CEC) than minesoils . CEC influences the quantity of exchangeable ions and, thus, affects soil fertility. The average CEC for natural soils was 8 meq/100 g while old, and new mine soils averaged 5 and 3 meq/100 g. The dominant clay minerals in natural soils have slightly greater cation retention as evidenced by the higher CEC/clay ratio.

Soil structure: Aggregation of primary soil particles into larger units is soil structure. The basic soil structural unit is the ped (Brewer, 1976). Formation of soil peds is favored by increasing clay and organic matter content (McHenry and Russell, 1943). In clayey soils, blocky structure develops rapidly in the subsoil. Prismatic structure develops in sandier soils (White,

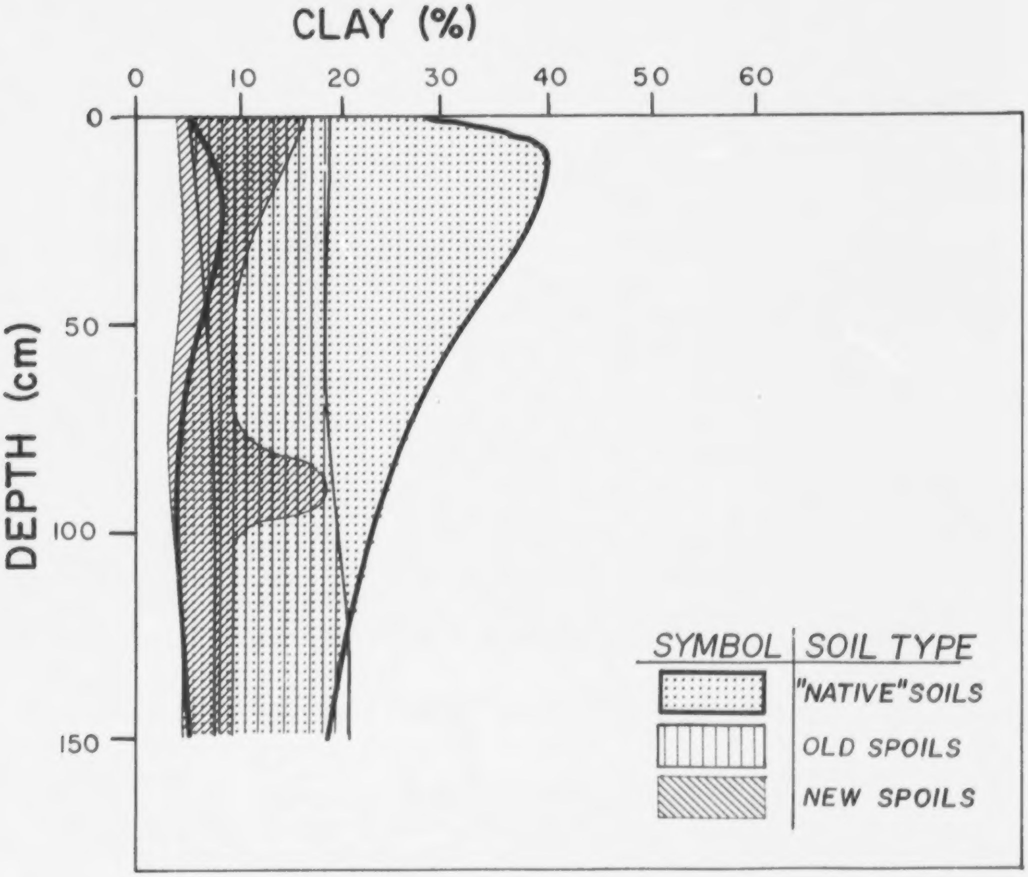


Fig. 25. Range in clay content for natural soils and minesoils .

1967). The arrangement of soil particles into larger peds decreases erodibility and increases pore space and thus infiltration. Formation of soil structure is, therefore, an important property affecting erosion and water movement.

Minesoils differ markedly from natural soils in the distinctness and kind of structural aggregates (Figs. 27 and 28). Most natural soils have moderate granular structure in the A horizon. Natural soils are massive below 130 cm where wetting and drying is infrequent and the weight of overlaying soil prevents formation of peds.

Weak platy and granular structure has formed in the upper 50 cm of many older minesoils . The platy structure may have resulted from compaction by heavy vehicle traffic. Granular structure is most prominent in association with the root systems of perennial grasses (Fig. 29). The relative strength or prominence of peds increases with increasing soil age indicating that

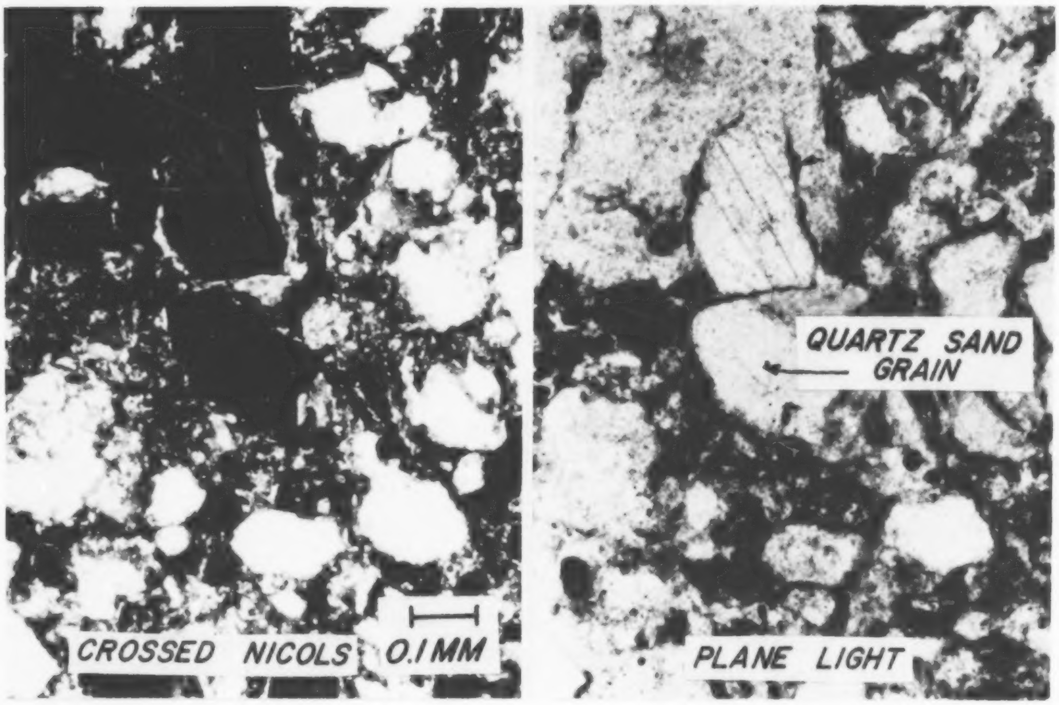


Fig. 26. Oriented clay (argillans) around sand grains of Boxwell B horizons.

structure begins to form in minesoils within 50 years. New minesoils with "topsoil" applied at the surface did not have granular structure which is common in A horizons of natural soils. The topsoil salvaging and replacement process destroys soil structure.

Some old spoils high in clay which were regraded in 1969 had vesicular structure in the upper 5 cm. Where slow infiltration causes the top few centimeters of soil to become saturated with water, air from lower in the soil is entrapped in the surface layer and forms spherical voids which cause vesicular structure when the surface dries to form a crust.

Bulk density: Old minesoils are nearly equal in bulk density to natural soils, but new minesoils have higher bulk density (Fig. 30). Density of mine spoils is related closely to the type of equipment used in regrading spoils as well as to soil texture and natural processes that mix or loosen soils.

Old spoils were deposited by side-dumping haul trucks. Materials were deposited at their angle of repose as platforms were built outward from a slope (Fig. 11). Many old spoils were compacted in the upper 30 cm due to repeated vehicle traffic; while below this depth they have low bulk density. The top 5 to 10 cm of old minesoils have decreased in bulk density due to

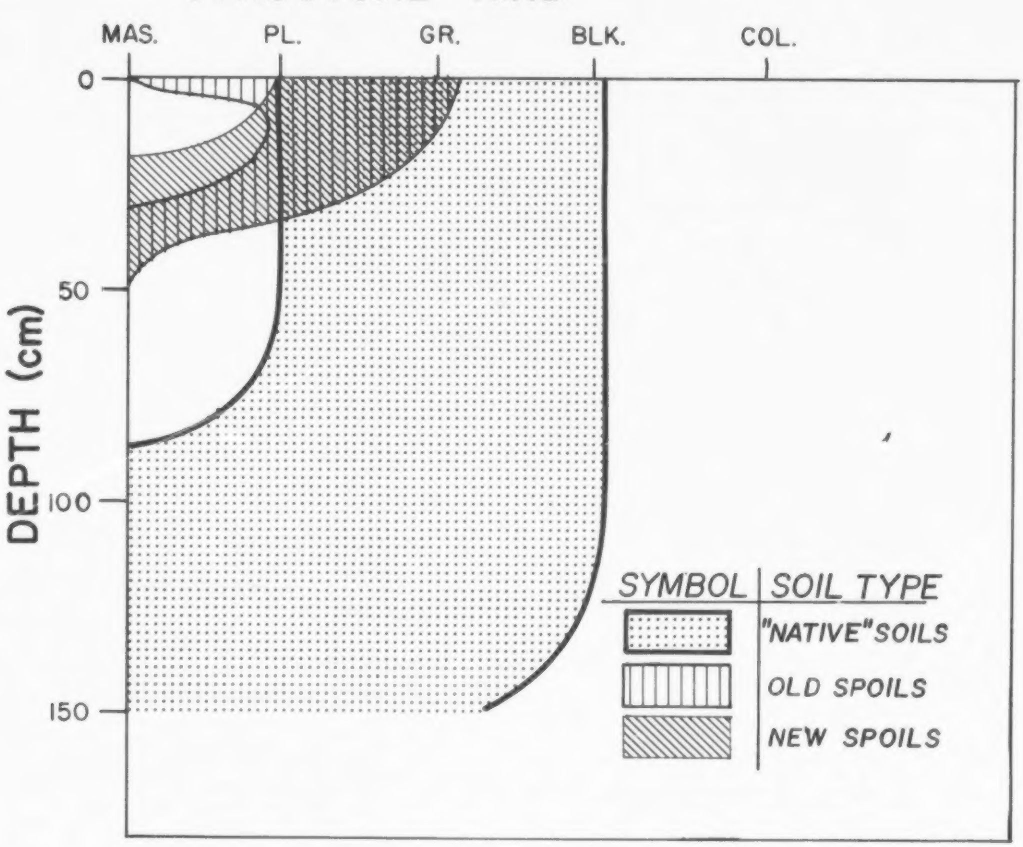


Fig. 27. Range in kinds of structure in natural soils and minesoils. (mas-massive, pl.-platy, gr-granular, blk-blocky, and col-columnar).

soil structure formation and incorporation of organic matter. New spoils were regraded with either bulldozers or scrapers (Fig. 31). Where spoil ridges were leveled, material deposited by draglines was uncovered. Scraper-deposited fine sandy loam and silt loam materials have the highest bulk density observed in the study (1.7 to 1.9 g/cm^3). A horizontal mat of roots has been observed above many of these compacted layers, indicating that root penetration was restricted. Other minesoils of similar texture but deposited by bulldozer had lower bulk densities (1.4 g/cm^3). Freezing and thawing may break up compacted zones above 30 cm within a few years after deposition.

Rock Fragments: Rock fragments comprise a major component of mine soils (Smith and others, 1976). Fragments in Colstrip minesoils are angular to rounded and average 3 to 5 cm in size. They consist of weakly-consolidated sandstone and siltstone, indurated sandstone, porcelanite, and coal (Table 4).

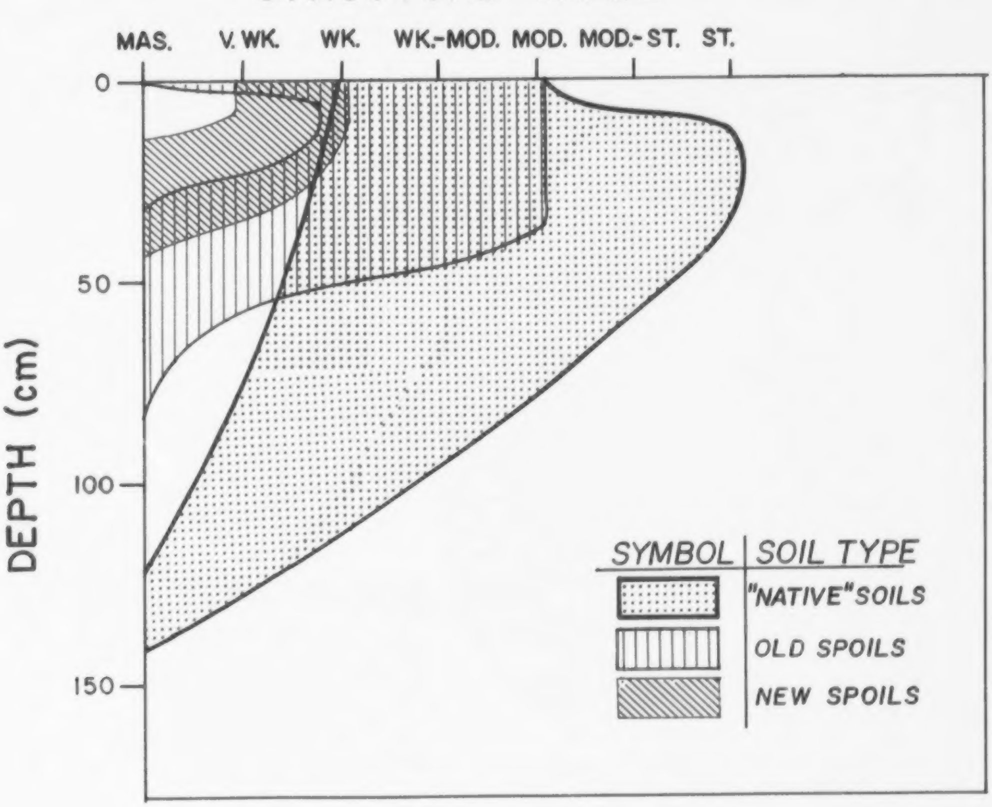


Fig. 28. Range in structure grade in natural soils and minesoils .

Unconsolidated rock fragments are unlike other rock fragments in that they hold a significant amount of plant-available water. Water is apparently withdrawn from fragments by plants during the growing season. Roots cannot penetrate into the fragments, however. Soft rock fragments respond in part like rock, and in part like soil. They are similar to materials which underlie paralithic contacts in local soils.

Soft rock fragments weather at a rapid rate in the upper layers of mine soils (Fig. 32). Rai and others (1974), in New Mexico and Grandt and Lang (1958) in Illinois found that shales weathered rapidly to create a clayey layer at the surface of spoils. The fine-textured crust increased run-off and was a limitation to reclamation. Rock fragments were weathered in the upper 20 cm of minesoils after 50 years in this study (Fig. 33). Soft sandstone appears to weather more rapidly than siltstone fragments. Porcelainite fragments are resistant to weathering as are indurated sandstone fragments. Coal does not disintegrate like other rock fragments, but may oxidize into leonardite-like material after exposure to weathering.

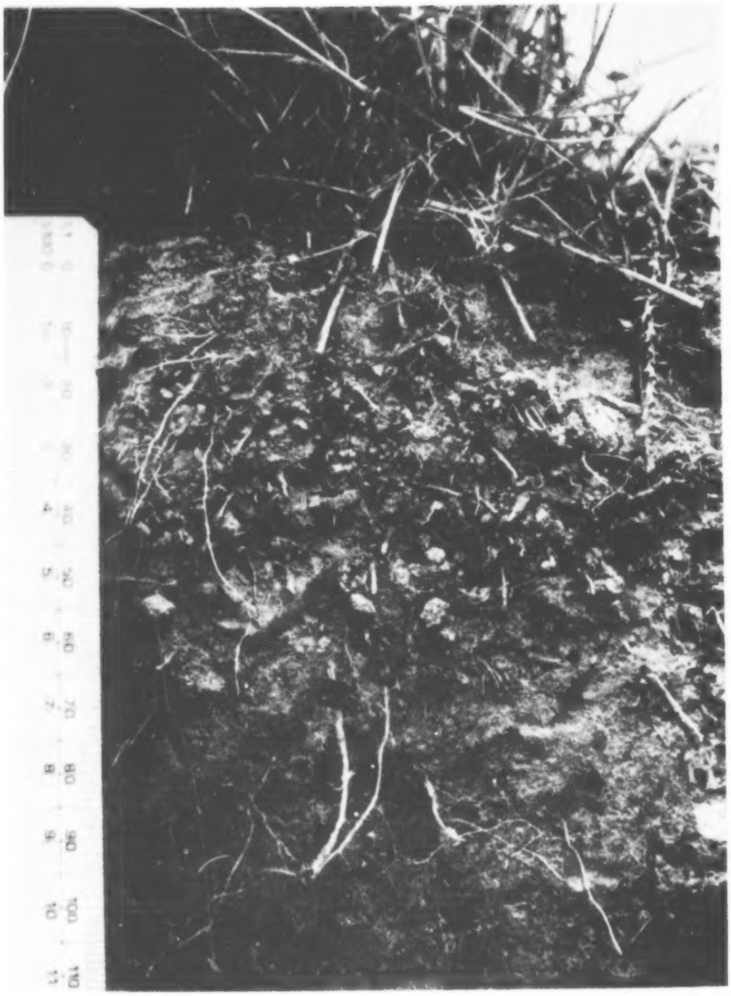


Fig. 29. Granular structure in old minesoils is associated with the root systems of perennial grasses.

Cycles of wetting, and drying; and freezing, and thawing; or mechanical disruption by roots may cause rock fragment weathering (Fig. 34). Workers at the University of Wyoming devised artifical weathering tests to evaluate the stability of rock fragments from overburden (Univ. of Wyo., 1976).

Thin sections of rock fragments from various depths were prepared to investigate the mode of rock weathering. Nearly unweathered fragments from 100 cm in 50-year old minesoils contain very little cement, so that simple grain-packing and compaction provides the only cohesiveness. Freezing and thawing, mechanical disturbance by roots, or expansion of clay minerals might provide sufficient energy to disintegrate fragments. Rapid wetting of fragments which entraps air causes fragments to slake in a few seconds or minutes.

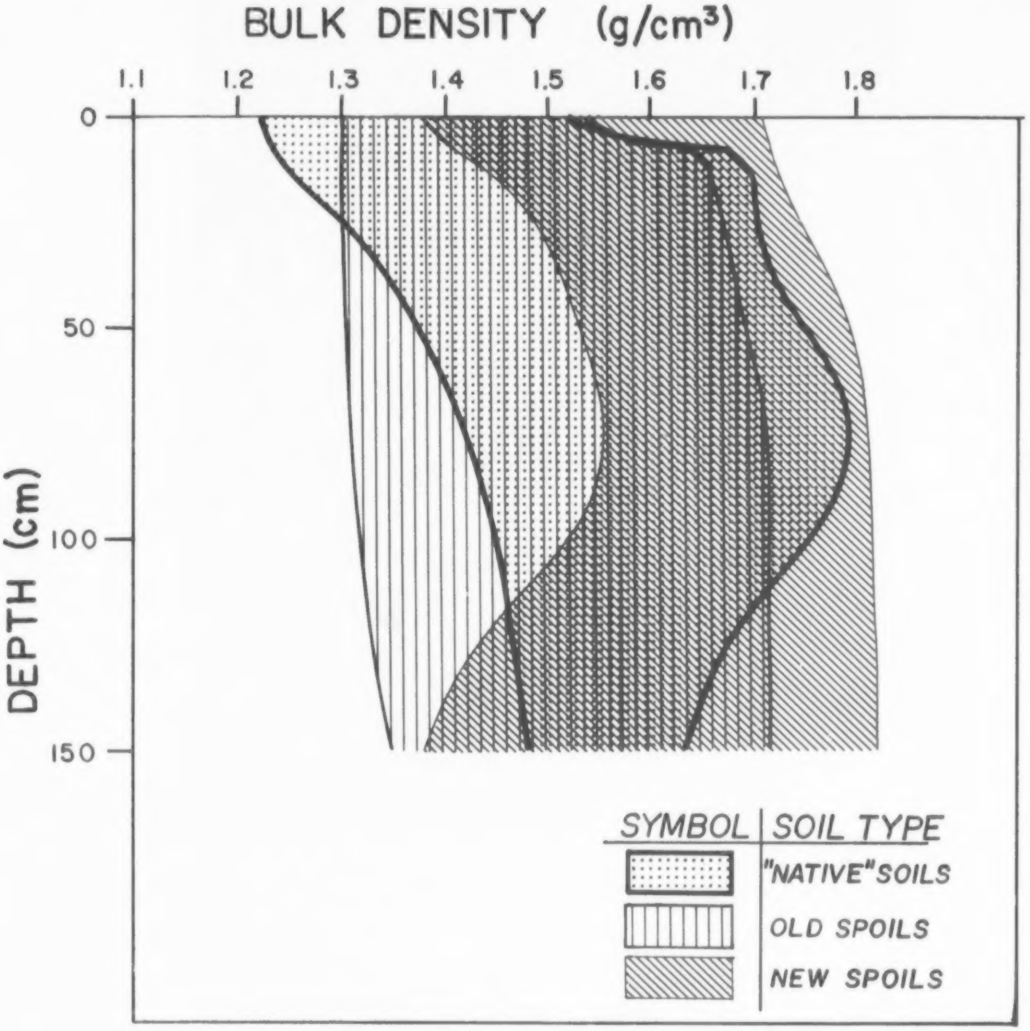


Fig. 30. Range in bulk density for natural soils and minesoils .

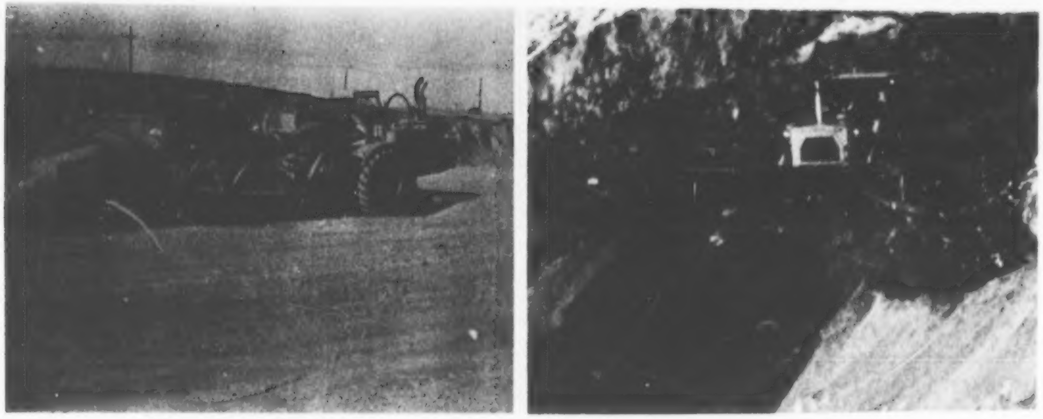


Fig. 31. Scrapers (left) and bulldozers (right) create minesoils with different bulk densities.

Nearly unweathered fragments from 100 cm contained approximately 10% calcite sand grains by volume. Weathered rock fragments from 20 cm in all minesoils contained fewer calcite grains. In weathered fragments, $CaCO_3$ is instead dispersed throughout the fragment as grain coatings of reprecipitated $CaCO_3$ (Fig. 35). Dissolution of 10% of the sand grains in the fragment could have caused disintegration. Further research on the role of rock fragments in minesoils is needed to evaluate their effect on plant growth.

Orphan Spoils

Many ungraded spoil ridges or "orphan spoils" are common in the Colstrip area. These steep spoils consist primarily of clayey materials from the pit bottom and are unlike the flattened platforms of excess overburden commonly referred to as old spoils throughout this report.

The vegetative cover on orphan spoils with similar slope and aspect was found to vary from 0 to nearly 100%. Cover was observed to decrease abruptly over a few feet of distance. A curious dark greasy-looking crust was observed on some non-vegetated areas (Figure 36). Several soil samples were collected from orphan spoils to see if soil properties would explain the lack of vegetation on some areas (Table 10).

Orphan spoils which supported vegetation were fairly similar to other mine soils in the Colstrip area. Non-vegetated spoils, however, had a much lower pH and higher EC than any other materials encountered in the area. Extractable levels of trace elements were similar to vegetated orphan spoils. Non-vegetated crusted spoils had extremely low pH (2.3 to 2.7) and EC greater than 15 mmhos/cm. Visible soluble salt crystals at the surface were probably magnesium sulfate. Magnesium content of a saturation extract generally exceeded 2000 ppm. Elevated levels of Mn, Zn, and Ni were found in crusted

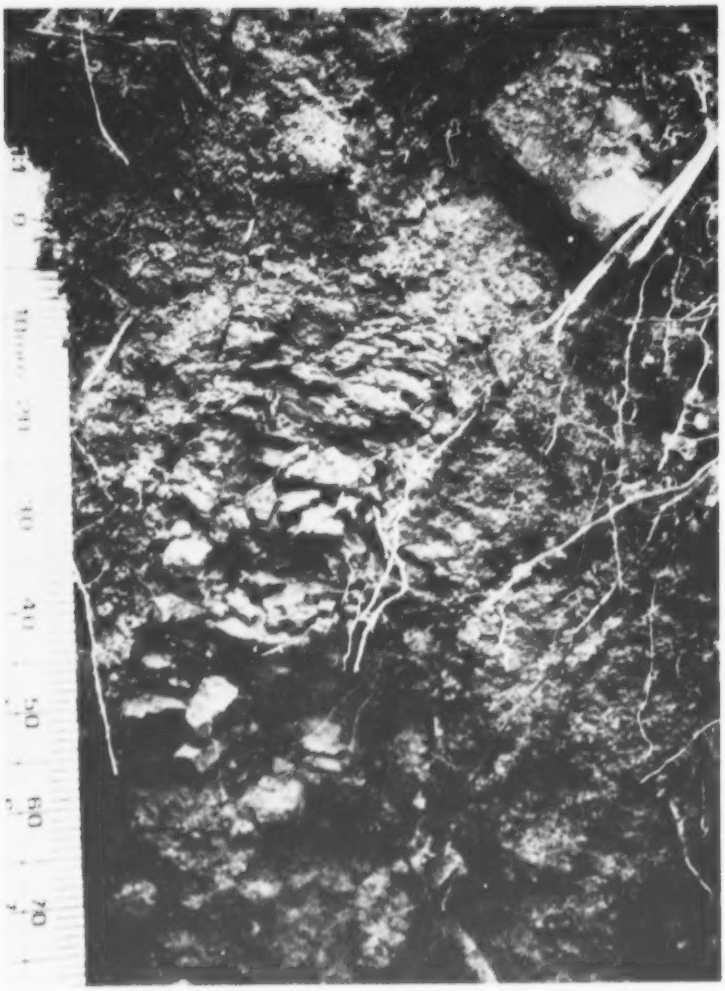


Fig. 32. A single shale fragment is shown to weather more quickly near the soil surface in this four-year-old minesoil.

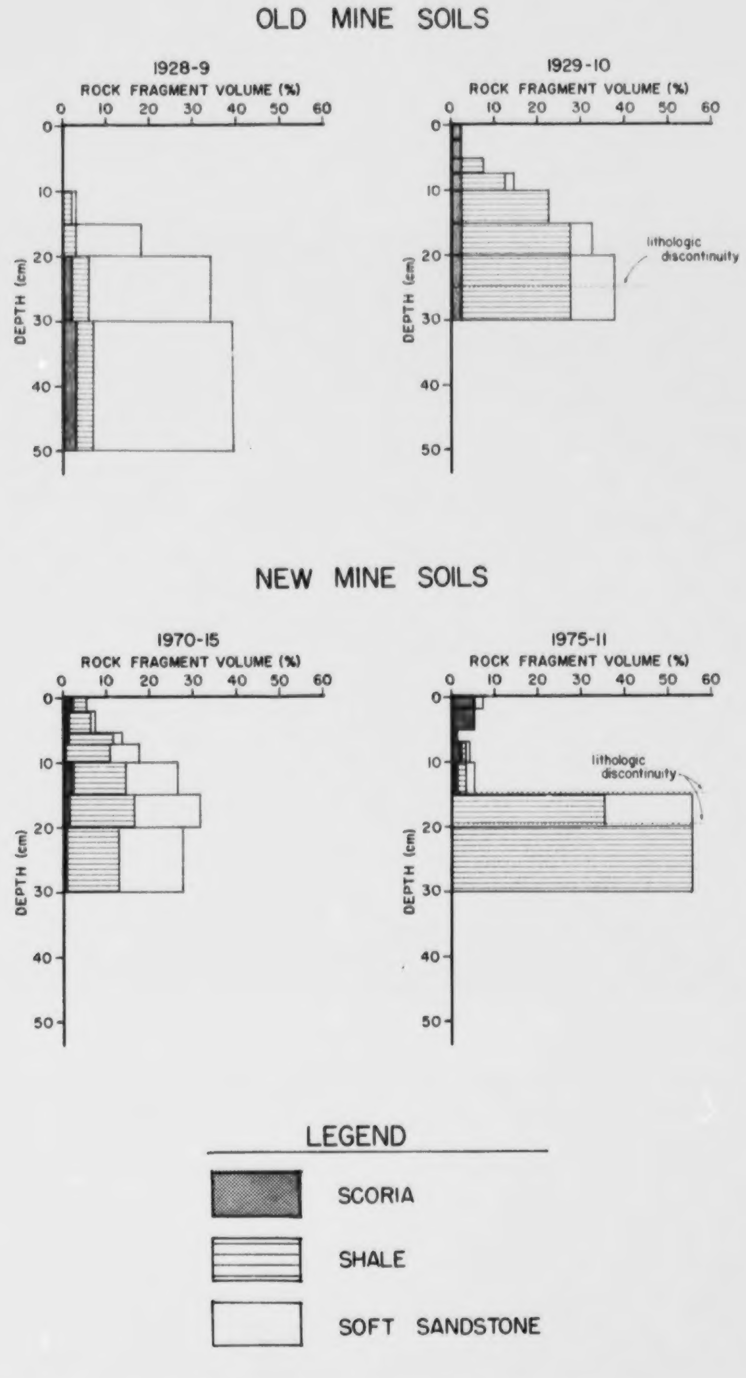


Fig. 33. Rock fragment content of minesoils varying in age.

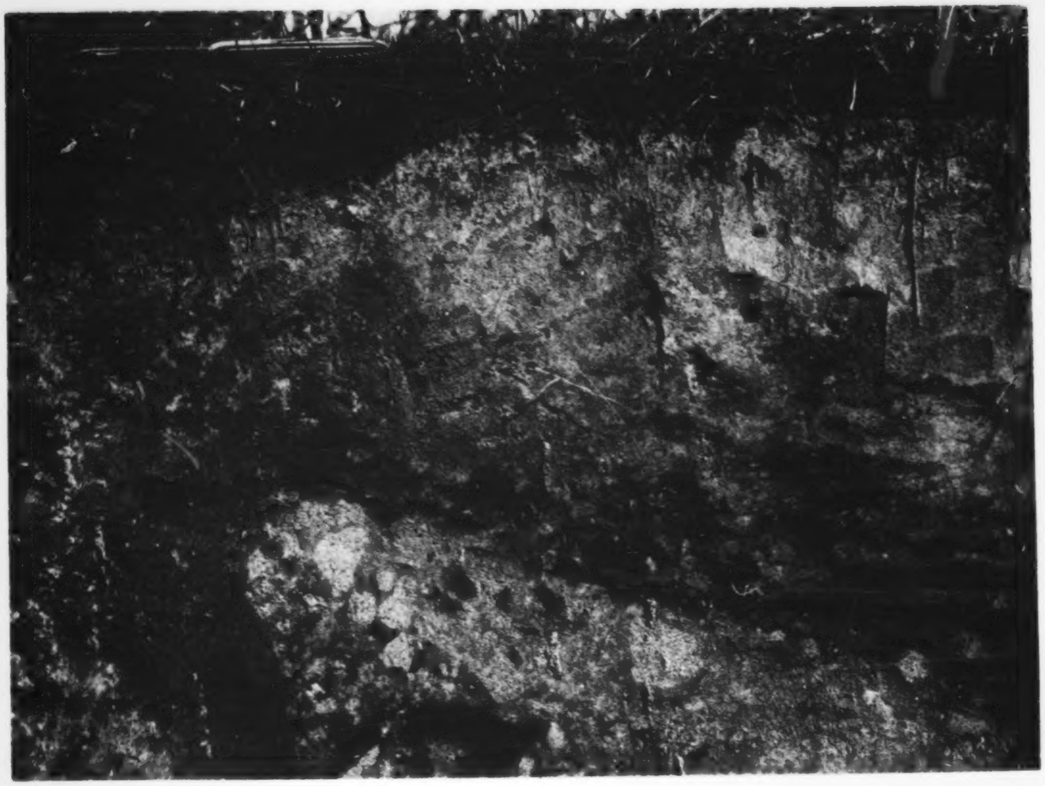


Fig. 34. Photo of 1928 minesoil showing that rock fragments have weathered in the upper 20 cm but are common below that depth.

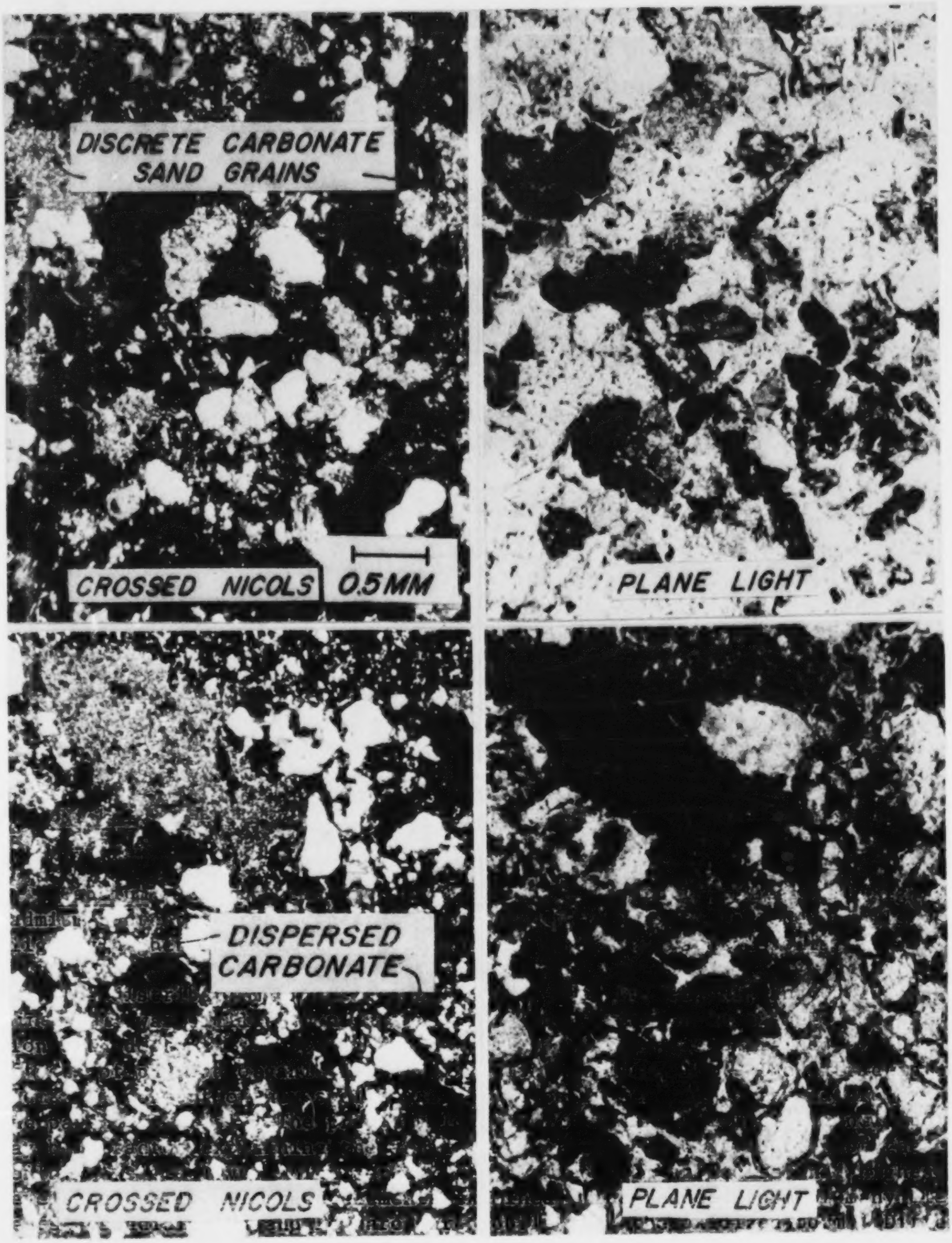

DISCRETE CARBONATE SAND GRAINS
CROSSED NICOLS
0.5MM
PLANE LIGHT
DISPERSED CARBONATE
CROSSED NICOLS
PLANE LIGHT

Fig. 35. Thin sections taken within unweathered (above) and weathered (below) sandstone fragments. $CaCO_3$ occurs in discrete grains in unweathered fragments but is dispersed in the weathered state.

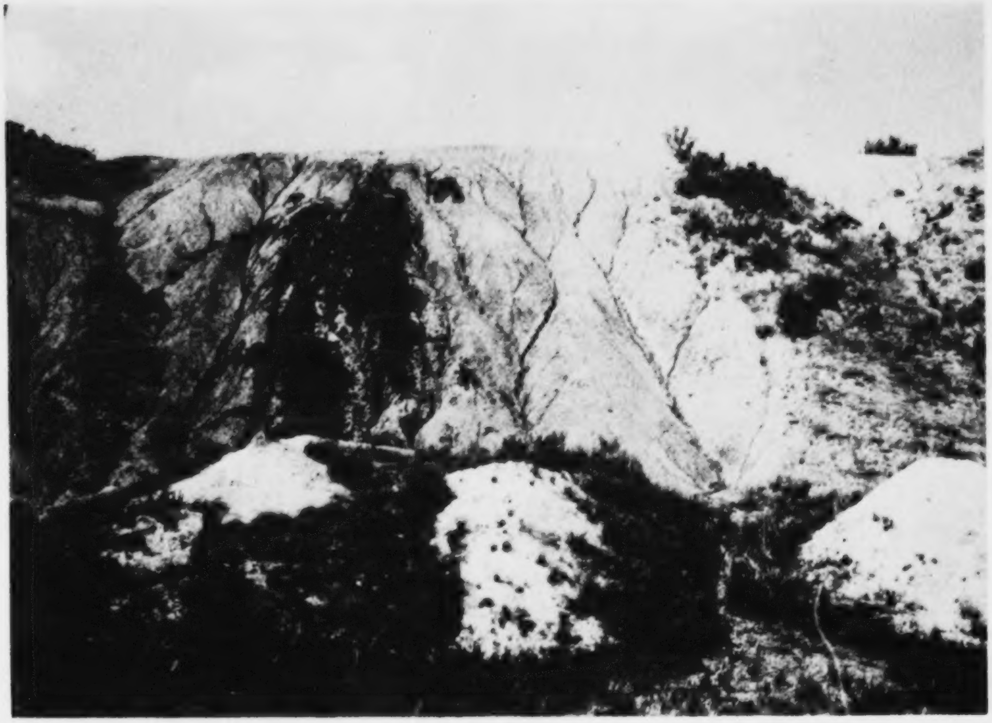


Fig. 36. Vegetated, non-vegetated, and crusted areas occur in close proximity on orphan spoils.

Table 10. Selected soil analyses from vegetated, non-vegetated, and non-vegetated, crusted orphan spoils in the Colstrip, Montana area.

				Saturation Extract			DTPA Extract						
	Depth (cm)	pH	EC (mmhos/cm)	Mg	Ca	Na	Mn	Cu	Zn	Pb	Cd	Ni	Fe
					mg/l					μg/g			
VEGETATED	0-2	5.6	.4	18.3	31.8	3.6	35.0	5.53	11.40	0.20	0.06	2.64	179
	2-5	7.3	.5	16.3	58.5	3.2	18.3	1.88	2.00	1.40	0.07	0.86	10.5
	5-10	8.3	.3	10.0	37.0	2.4	11.5	1.74	1.16	1.24	0.05	0.78	6.9
NON-VEGETATED	0-2	3.9	1.4	67.5	95.4	8.1	38.9	5.36	9.40	0.14	0.06	3.02	210
	2-5	4.1	.9	49.6	67.2	4.2	39.2	3.55	8.10	0.14	0.12	3.20	172
	5-10	7.6	.8	31.7	84.5	3.3	24.4	2.12	3.30	2.00	0.10	0.88	15.7
NON-VEGETATED CRUSTED	0-2	2.7	>15.0	2620	63.8	2.0	103.6	3.55	18.84	0.36	0.10	5.20	715
	2-5	2.3	>15.0	2880	54.5	1.2	86.9	2.02	18.80	0.40	0.11	5.50	1100
	5-10	2.3	>15.0	1333	81.0	2.1	61.0	1.67	13.84	0.36	0.08	3.10	831

non-vegetated spoils. Manganese and Ni concentrations exceeded levels suspected of causing phytotoxicity (MDSL, 1977).

The low pH in orphan spoils probably resulted from the oxidation of pyrite which is often concentrated in the upper few feet of the coal seam. Because of a lack of sufficient water to leach the spoil, salts accumulated as products of pyrite oxidation. At the low pH in these spoils, it is possible that some clay minerals or other silicate minerals were rapidly weathered to produce the high Mg contentof the spoils. Sulfate is a direct product of pyrite (FeS_2)oxidation. The dark crust results from the presence of free sulfuric acid which combines hygroscopically with water causing the soil surface to remain wet. Salts associated with a similar crust which forms in minesoils of the eastern US (Fanning and others, 1977) included halotrichite ($FeAl_2\ (SO_4)_4 \cdot 22H_2O$) and kalinite ($KAl(SO_4)_2 \cdot 11H_2O$).

It is often assumed that high sulfur content in conjunction with high precipitation causes the low pH which forms in eastern spoils. Formation of acid spoils in this climate, however, suggests that the acid-base balance in the overburden may be more important than precipitation in acid formation (Smith and others, 1976). Caruccio (1978), and Arora and others (1978) report that pyrite morphology also influences acid-producing potential. The high calcium carbonate content of spoils in the West apparently provides enough buffering capacity to prevent acid-formation except when large amounts of pyritic coal is mixed with the overburden.

SECTION 8

WATER RELATIONS

Availability of soil water for plant growth is a major limitation to Western reclamation (Hodder, 1978). Precipitation is a primary factor influencing the amount of soil water in western minesoils . Soils with low infiltration rates will not absorb precipitation during high intensity storms or snowmelt. Run-off from these types of soils can result in severe erosion especially on unvegetated sites.

Once water enters the soil, its movement is governed by water potential gradients. Water potential is a measure of the energy state of water in soil. It is influenced by gravity, salt content, matric potential, and other factors. In a saturated soil, water moves downward to the water table under the influence of gravity. Mine soils in the West are seldom, if ever, saturated. In these soils, water moves by unsaturated flow which can be upward, downward, or lateral in direction. Water moves from zones which have a high water potential to those with lower potentials. In unsaturated soils, this means that water moves to zones that are drier or higher in salt than the surrounding soil. As plant roots extract water from soil, a water potential gradient is produced which causes water from other soil zones to flow toward the root. The rate of flow especially in dry soils is very slow. As a result, roots can extract a substantial amount of water only from a soil volume several cm in diameter. Therefore, compacted soil horizons which impede deep penetration of roots may severely limit the water available to the plant. Likewise, a young plant community without a well-developed root system probably has less water available to it for growth.

In this study, the water movement patterns in old, and new minesoils ; and natural soils have been observed. Differences in water movement were related to soil physical properties and root distribution to evaluate how minesoils differ from natural soils hydrologically.

Infiltration

Infiltration rates on all soils studied varied from 6 to 15 cm/hr (Table 11, Appendix B). There were no significant differences between infiltration rates on undisturbed soils and minesoils . Differences in infiltration rates between individual sites were highly correlated with surface sand content ($r = .85$) and silt content ($r = -.84$).

Infiltration into minesoils was not slower than into natural soils as has been shown by other studies in the region (Gilley and others, 1977b; Dollhopf and others, 1977; Arnold, 1977; Miyamoto, 1977). Moderately rapid infiltration rates (Soil Survey Staff, 1951) can apparently be attained

Table 11. Infiltration rate after 30 minutes on natural soils and minesoils of the Colstrip, Montana area. Reported values are the mean of three replicates.

SITE	SOIL TYPE	INFILTRATION (cm hr^{-1}) *
1975-11	new spoil	5.93 a
Ethridge-4	natural spoil	8.20 b
1929-10	old spoil	8.90 b
Boxwell-2	natural soil	10.63 c
1928-9	old spoil	11.83 d
1928-7	old spoil	12.43 d
1973-12	new spoil	14.00 e
Chinook-8	natural spoil	14.23 ef
Riedel-6	natural spoil	14.87 ef
1970-15	new spoil	14.87 ef
1972-13	new spoil	15.30 f

* numbers followed by the same letter are not significantly different at $p < .05$.

quickly on minesoils by using non-sodic, coarse-textured surface materials. The presence of impermeable subsoil layers would be expected to eventually decrease infiltration rates (Gilley and others, 1977b).

Even though infiltration is moderately rapid on Colstrip minesoils, erosion is still common in the mine area. Fine and very fine sand, which is dominant in these soils, is easily entrained by running water. Therefore a small amount of run-off occurring as a result of high intensity storms can cause severe erosion. Rapid establishment of vegetation is mandatory for erosion control even on minesoils with moderately rapid infiltration.

Water Flow Patterns

Precipitation patterns during 1976 and 1977 allowed the soils to be observed under two climatically different years. A wet spring and dry summer occurred in 1976 with precipitation 111% and 30% of normal for the two periods. In 1977, a dry spring (62% of normal) was followed by a wet summer (146% of normal, Fig. 37).

A similar general pattern of water use occurred in all soils. Maximum water content was observed in April after snowmelt and initiation of spring rains. Most of the profiles were recharged with water to at least two meters. As soil temperature increased, water was withdrawn from the shallowest soil depths by growing plants. As water in surface horizons was depleted, the zone of maximum water use shifted to progressively deeper depths. By late summer soils were at their driest; plant-available water was depleted from much of the root zone. Little change in water content occurred during most of the fall and winter. Only a small amount of recharge occurred in the upper 30 to 50 cm during this period. During the coldest winter months, water content was observed to increase in the upper 50 cm and again decrease by early spring. This phenomenon has been noted in other frozen soils in the

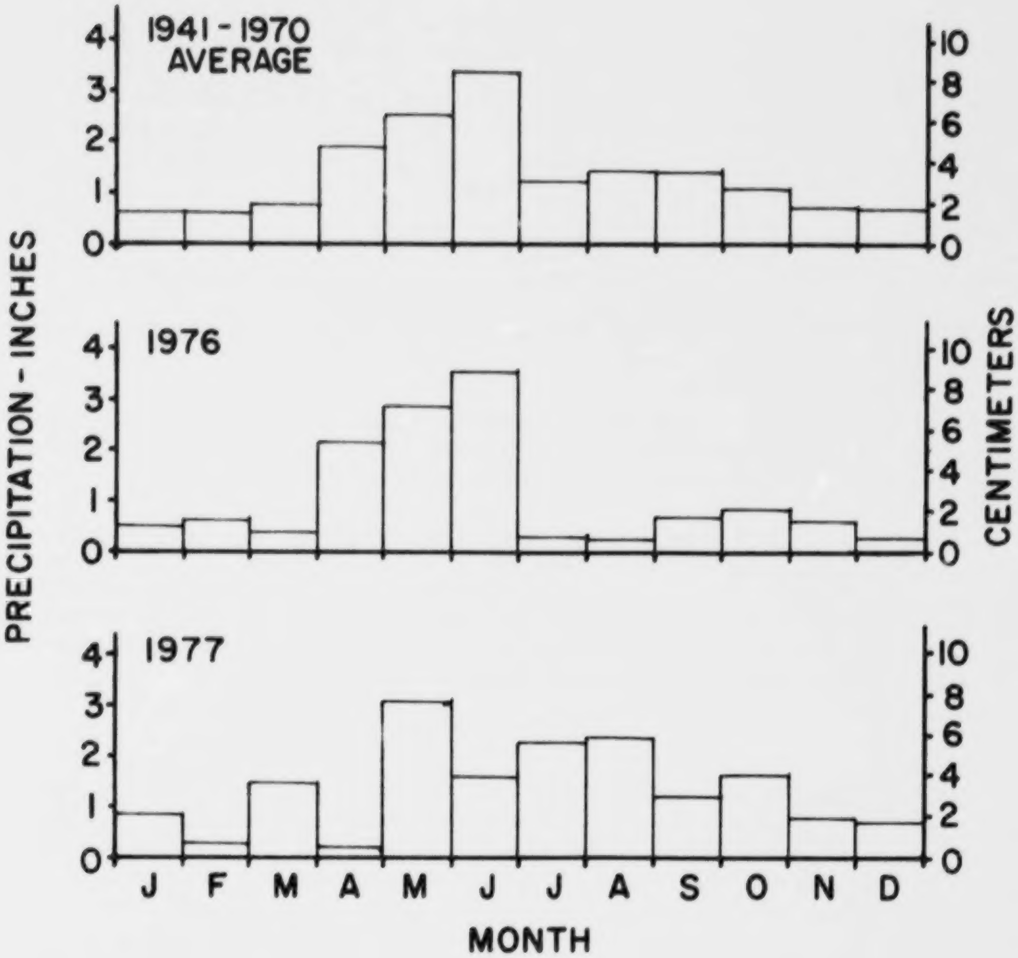


Fig. 37. Average monthly precipitation is shown in comparison to 1976 and 1977 totals.

Northern Great Plains and has been related to water vapor movement in response to temperature gradients (Ferguson and others, 1964; Willis and others, 1964).

Although the general pattern of water movement was similar in all soils, the magnitude of recharge, stored soil water, water use, and the timing of these events differed in old and new minesoils, and natural soils. For example, in Fig. 38 the stored soil water in the upper 150 cm of the soils is shown as a percentage of the maximum recharged level observed early in 1976. Approximately 50% of the stored soil water should be available for plant growth. It is apparent that water is used more rapidly from minesoils than natural soils during the summer of 1976. The rate of water use in new mine soils declines by mid-summer so the total depletion is similar to natural soils. Depletion continues in old minesoils, however, until nearly all available water is withdrawn from the upper 150 cm. As a result of these water removal patterns, only limited recharge occurred in old minesoils during the dry spring of 1977. Thus less total water was available in the drier year. New minesoils were also recharged slightly less than natural soils.

Differences in water use are probably largely a result of differences in plant communities. Natural soils support a mixture of cool- and warm-season native grasses, with some forbs and shrubs; which use water very conservatively. Water removal begins more slowly in the spring when use by introduced species on new minesoils is rapid. Water use in natural soils continues through the summer by warm-season grasses, forbs, and shrubs. New minesoils are dominated by introduced perennial grasses with some introduced shrubs. These grasses such as *Bromus inermis*, *Agropyron cristatum*, and *A. elongatum* are characterized by early growth. As a result, water is used rapidly in the spring but decreases to near zero by mid-summer when these species enter summer dormancy. Old minesoils are dominated by shrubs, half-shrubs, and annual grasses. This plant community tends to withdraw water early in the spring, but continues to remove water throughout the growing season. By late summer, nearly all plant available water is withdrawn from the upper 150 cm. Only deep-rooted shrubs are adapted to growing in these conditions. As a result of this nearly complete use of soil-water in a wetter-than-normal year, only partial recharge of soil water occurred in 1977, a dry year. Community production would be expected to be most variable and unstable on old minesoils due to the water use patterns. Plant communities on natural soils which use water more conservatively would be expected to have lower productivity in a wet year than plant communities on mine soils, but higher than minesoils in a dry year because more complete recharge would occur.

Observation of water content by depth shows the dynamics of water use with more detail (Figures 39-53). Bulk density and root biomass of the soils are shown to aid in the understanding of water distribution patterns.

During May and June, water is used from the upper 50 cm of natural soils where the soil is warmest and roots most abundant. The zone of maximum water use shifts downward to 100 cm by mid-summer. Late in the summer only a small amount of available water is left in the upper 50 cm, however, only small

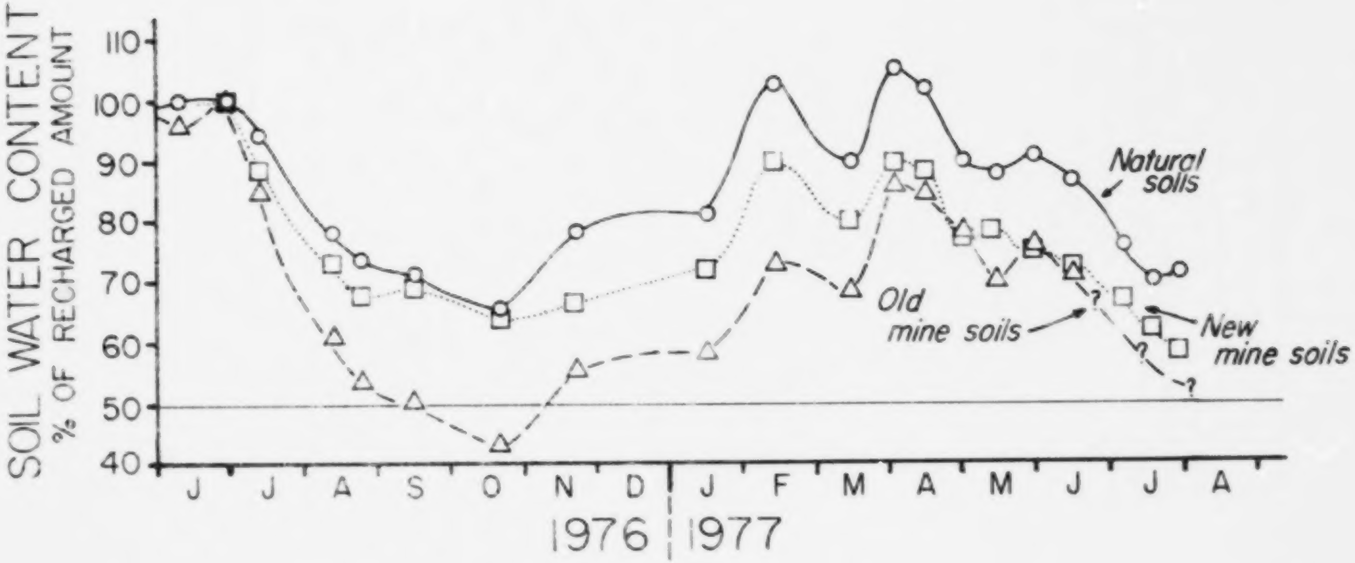


Fig. 38. Profile water content (cm in upper 150 cm) is shown as a percentage of the recharged content in June, 1976. The line at 50% represents the approximate wilting point.

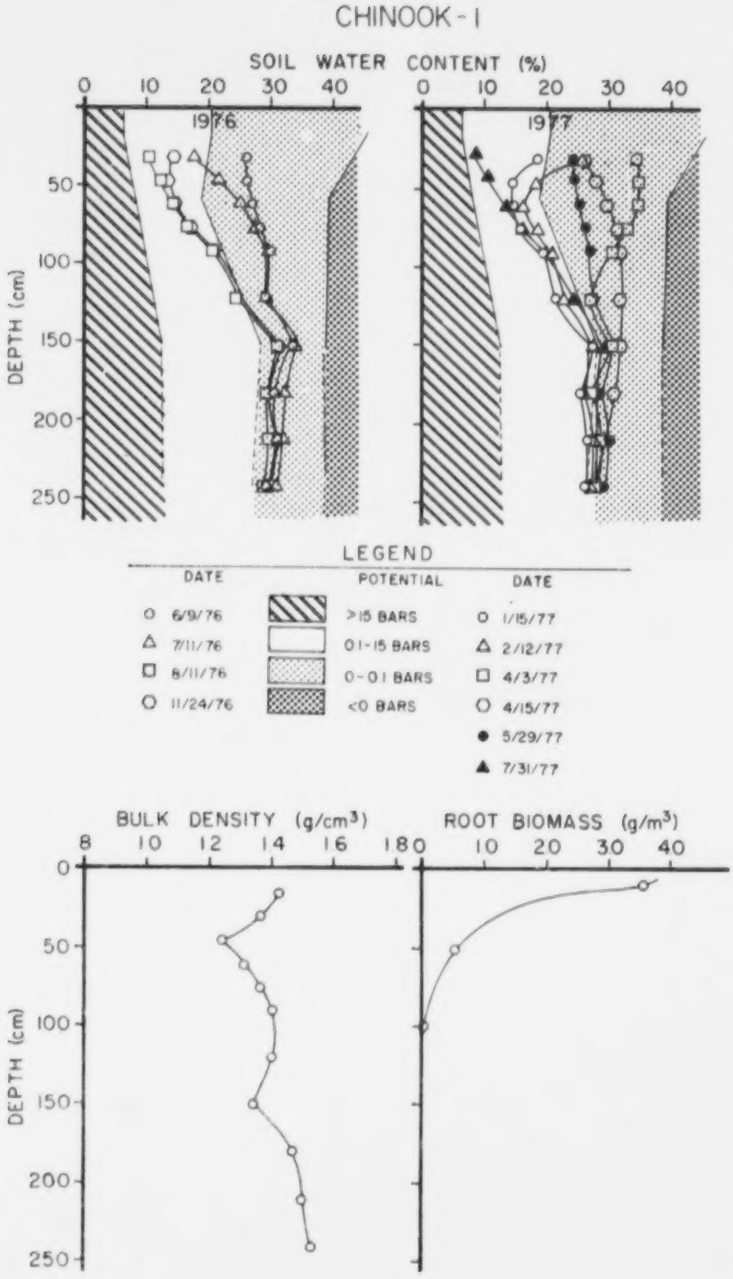


Fig. 39. Seasonal water content, bulk density, and root biomass for the Chinook-1 soil.

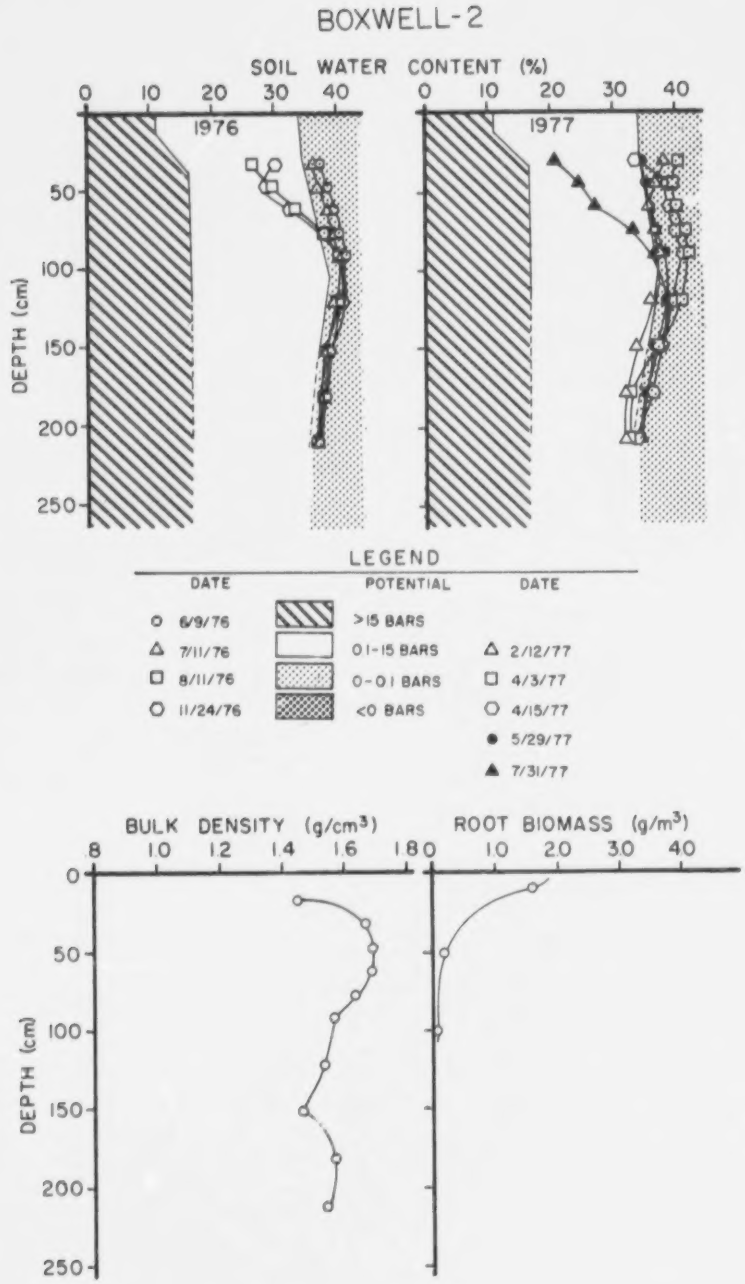


Fig. 40. Seasonal water content, bulk density, and root biomass for the Boxwell-2 soil.

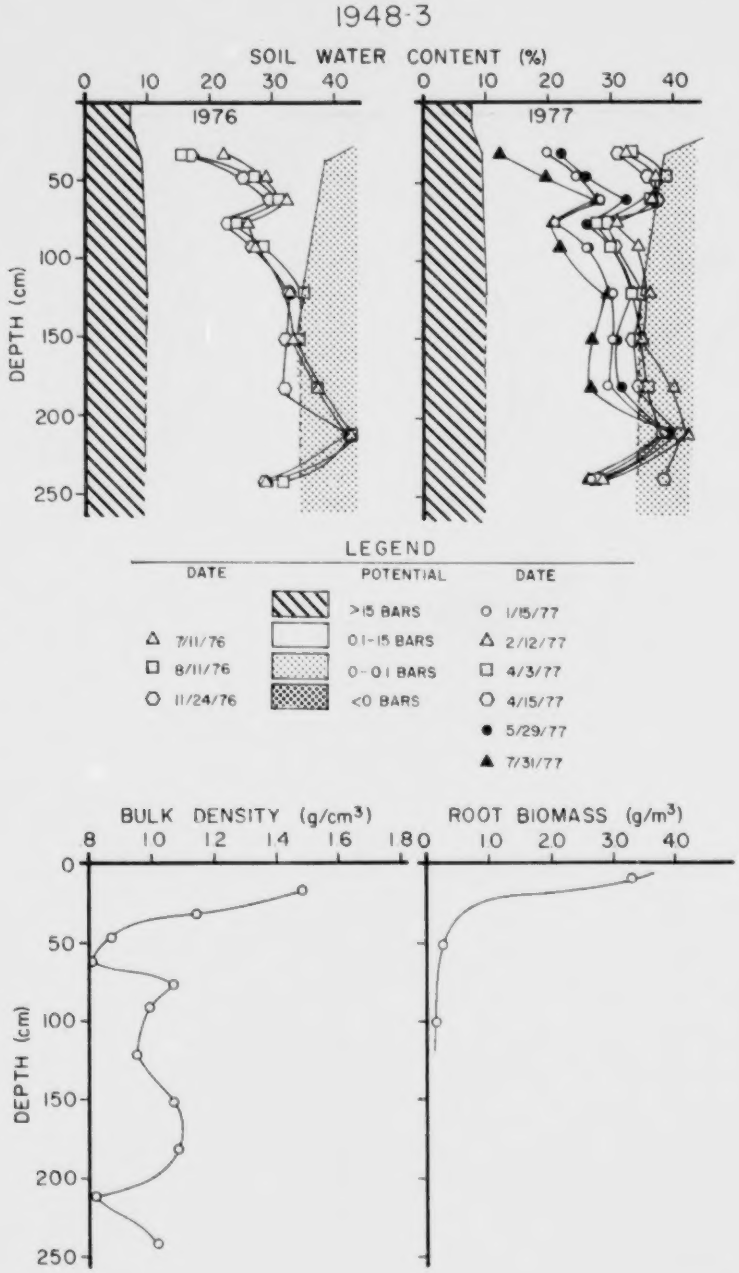


Fig. 41. Seasonal water content, bulk density, and root biomass for the 1948-3 soil.

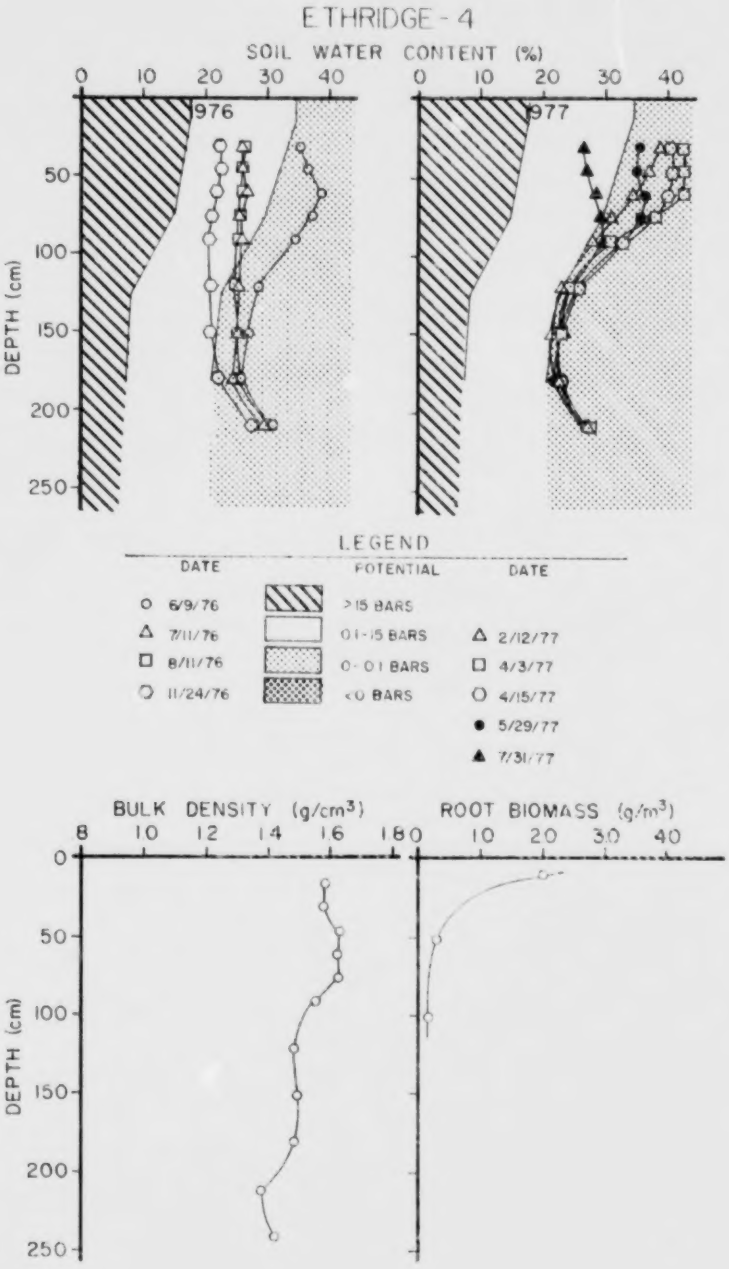


Fig. 42. Seasonal water content, bulk density, and root biomass for the Ethridge-4 soil.

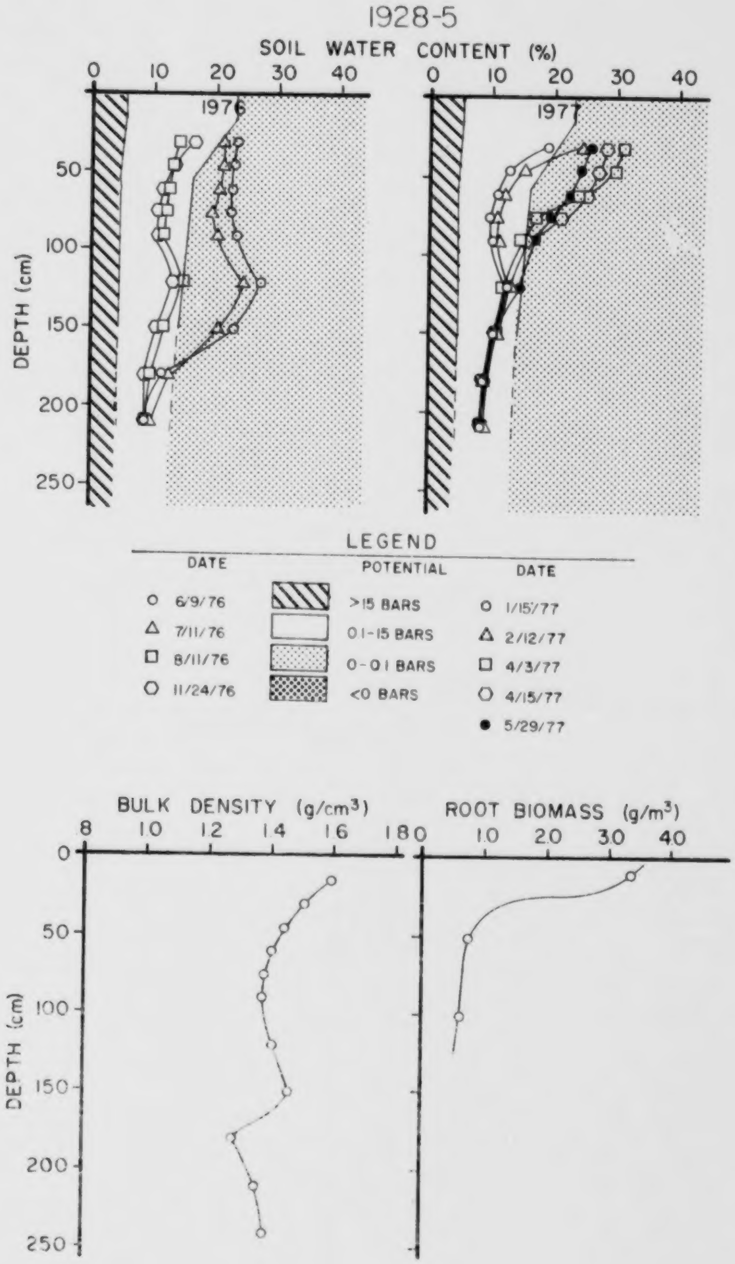


Fig. 43. Seasonal water content, bulk density, and root biomass for the 1928-5 soil.

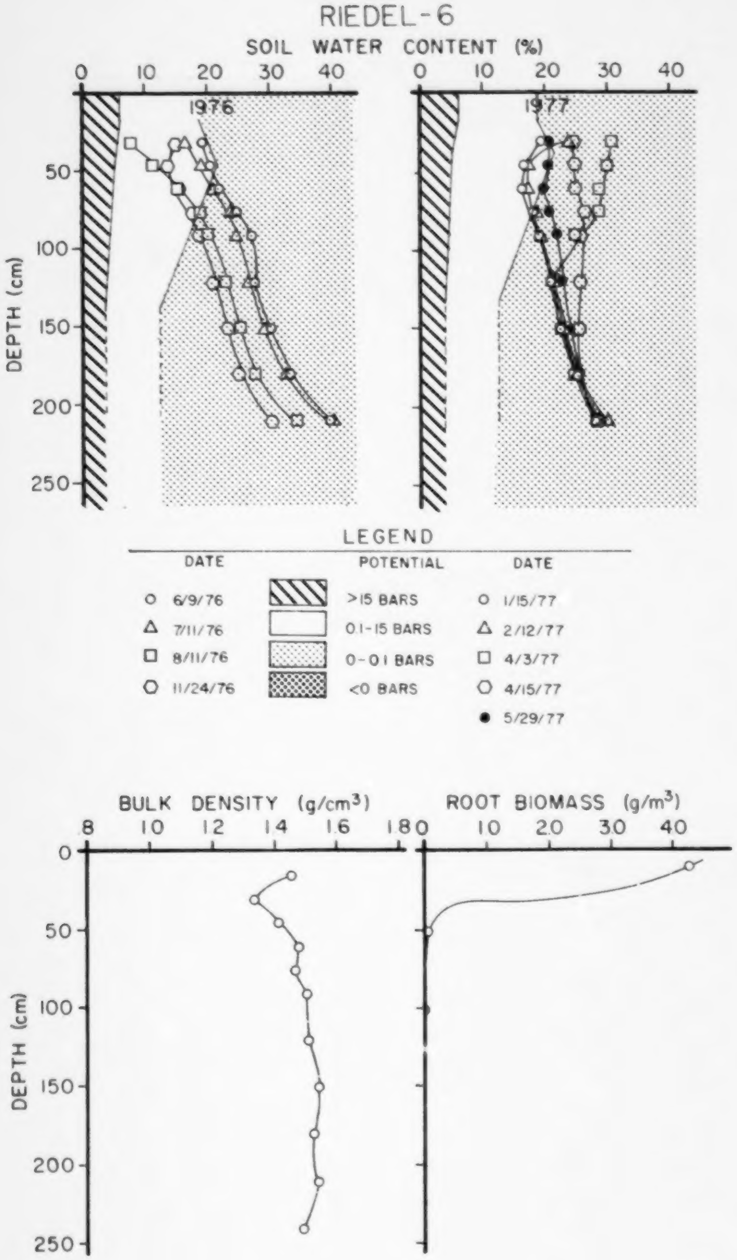


Fig. 44. Seasonal water content, bulk density, and root biomass for the Riedel-6 soil.

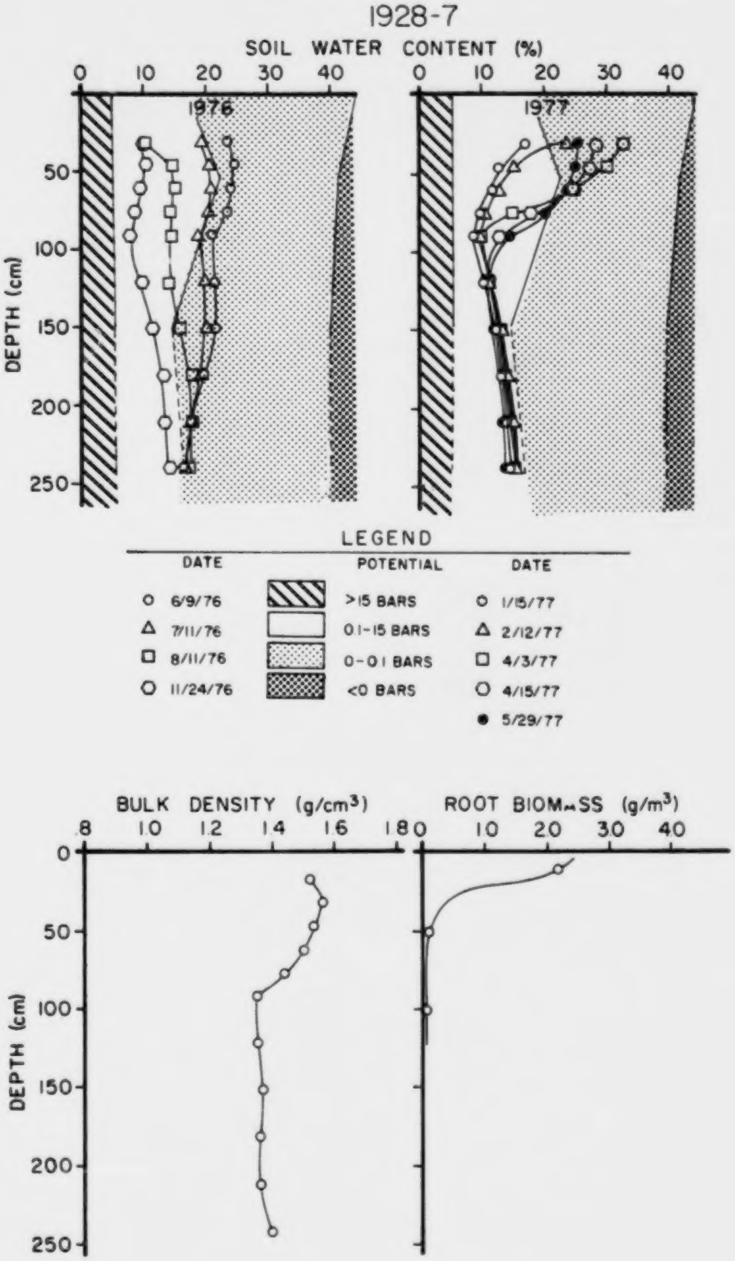


Fig. 45. Seasonal water content, bulk density, and root biomass for the 1928-7 soil.

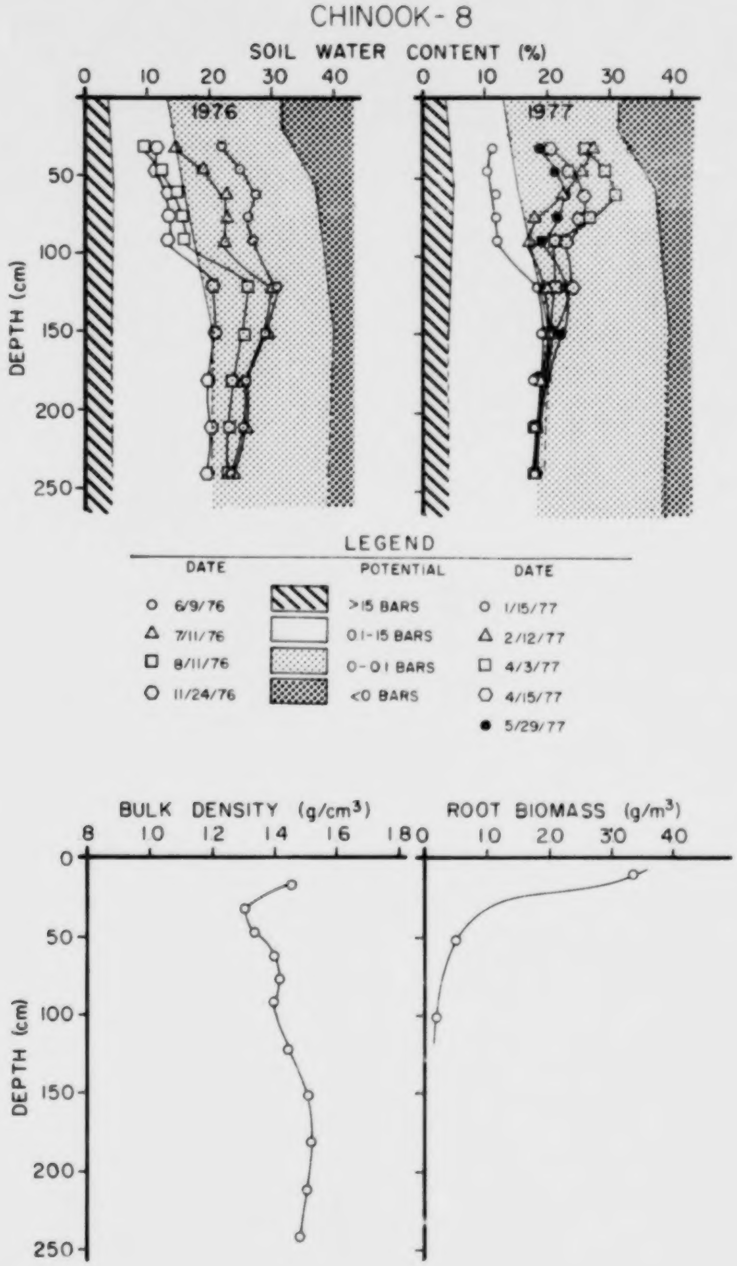


Fig. 46. Seasonal water content, bulk density, and root biomass for the Chinook-8 soil.

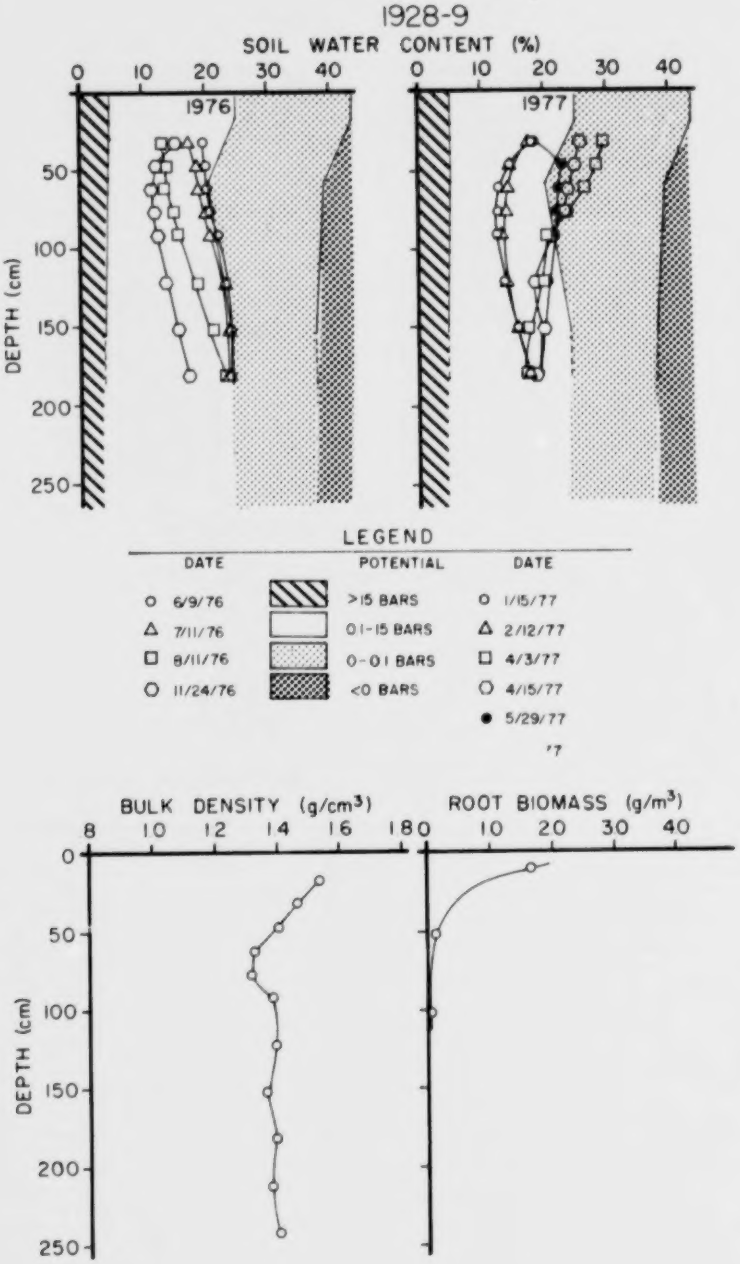


Fig. 47. Seasonal water content, bulk density, and root biomass for the 1928-9 soil.

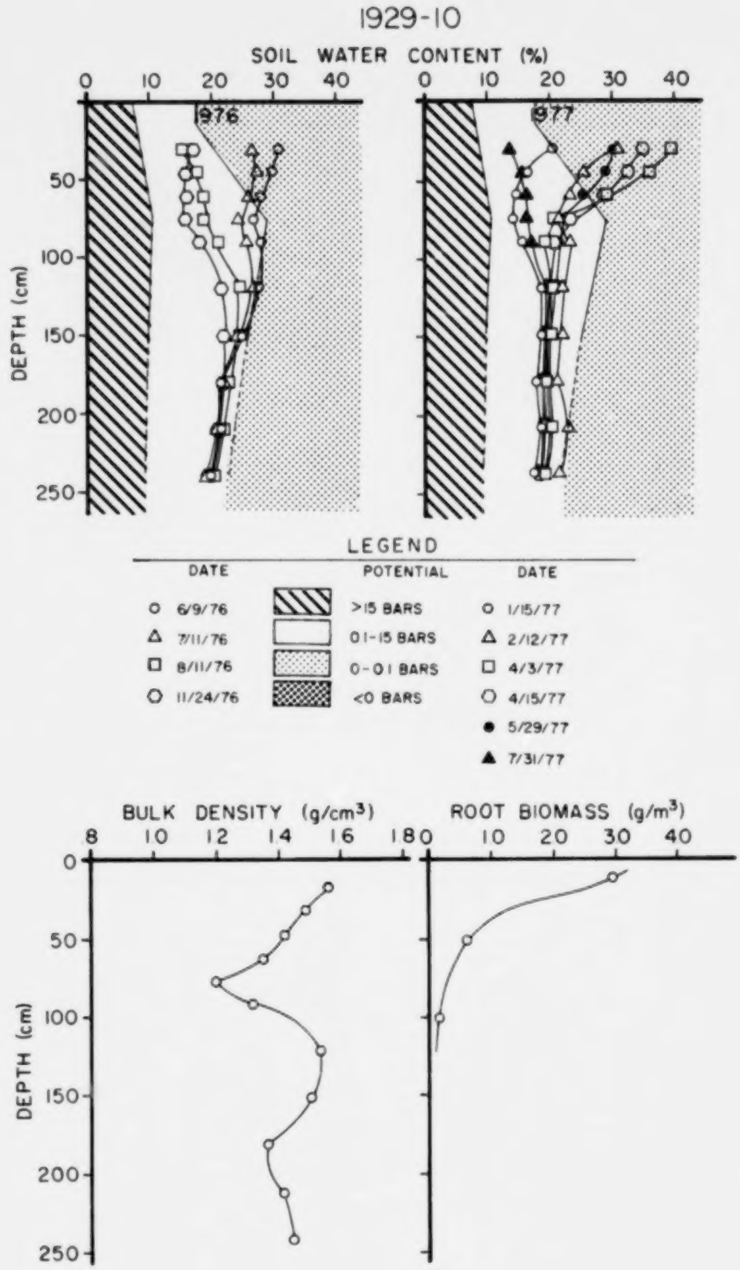


Fig. 48. Seasonal water content, bulk density, and root biomass for the 1929-10 soil.

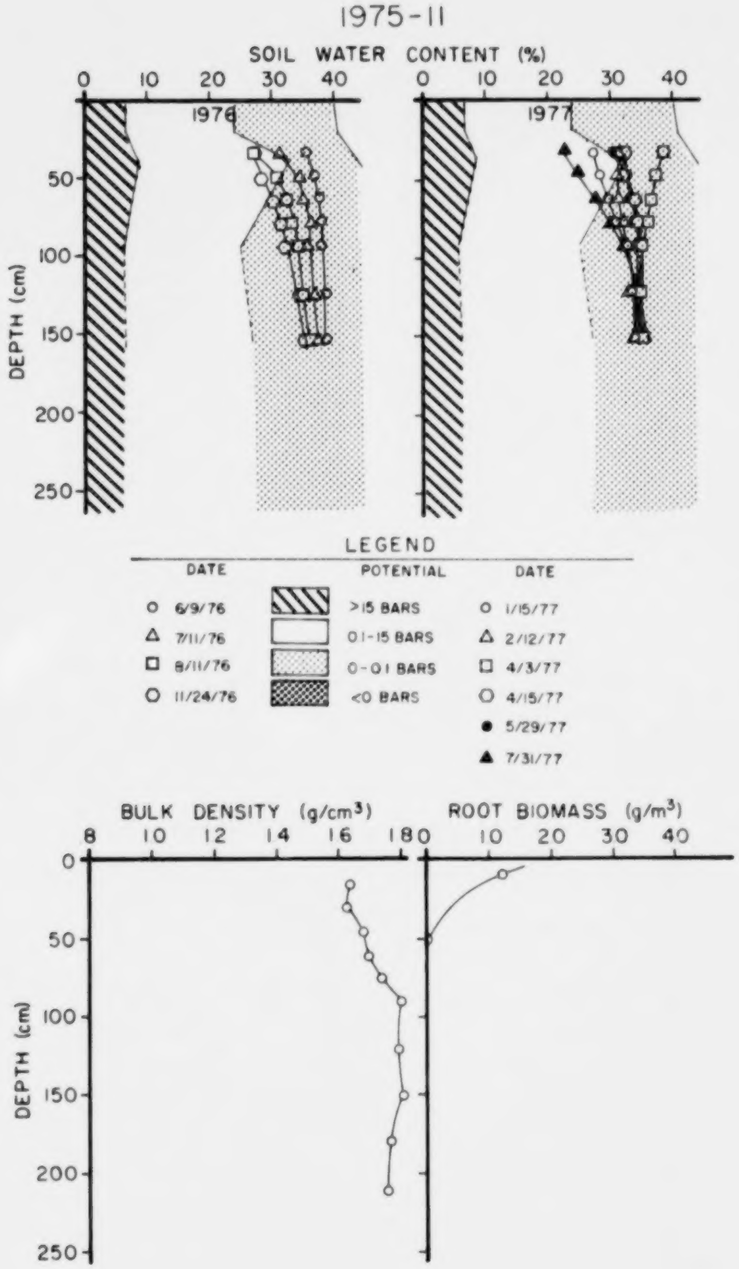


Fig. 49. Seasonal water content, bulk density, and root biomass for the 1975-11 soil.

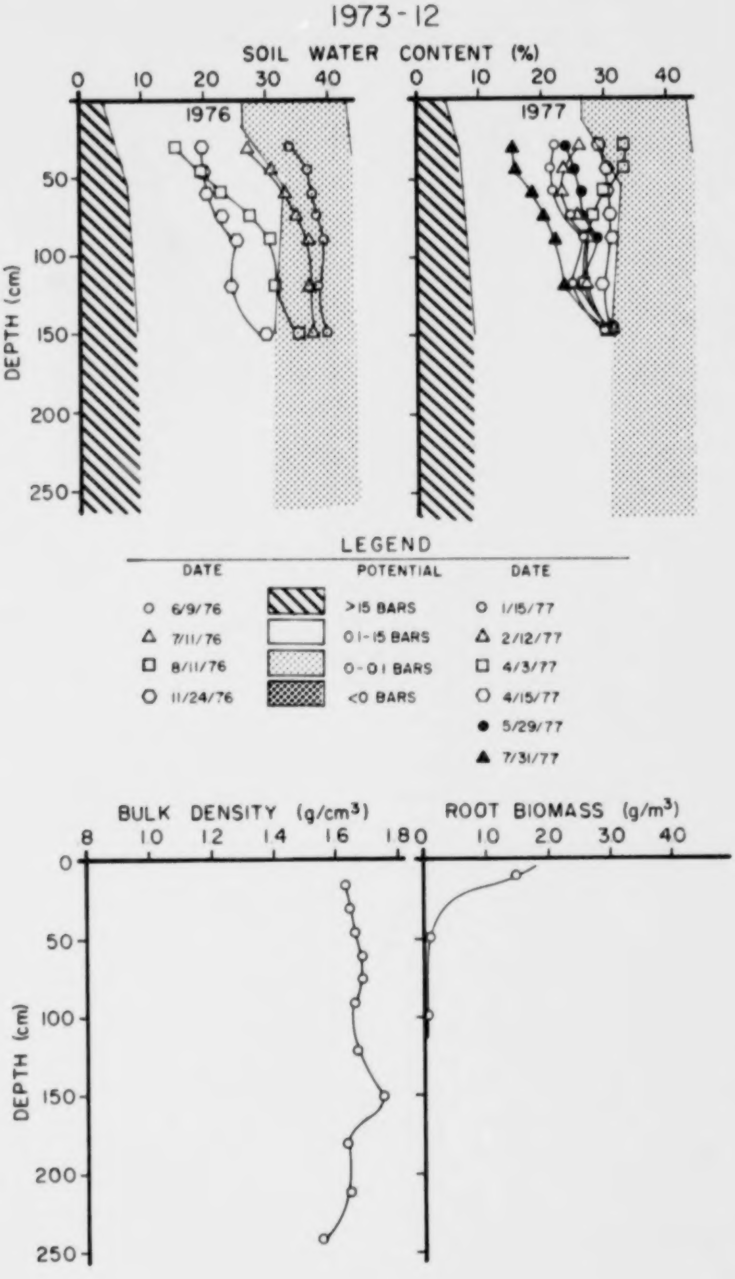


Fig. 50. Seasonal water content, bulk density, and root biomass for the 1973-12 soil.

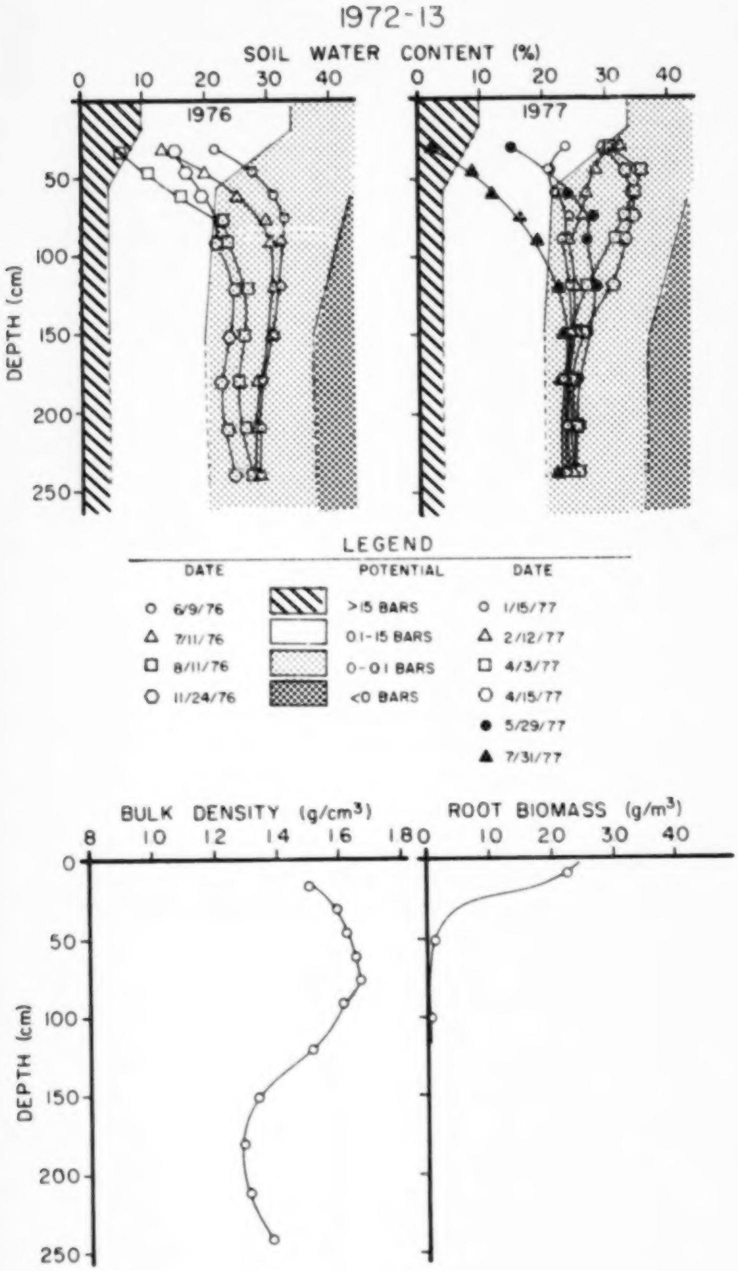


Fig. 51. Seasonal water content, bulk density, and root biomass for the 1972-13 soil.

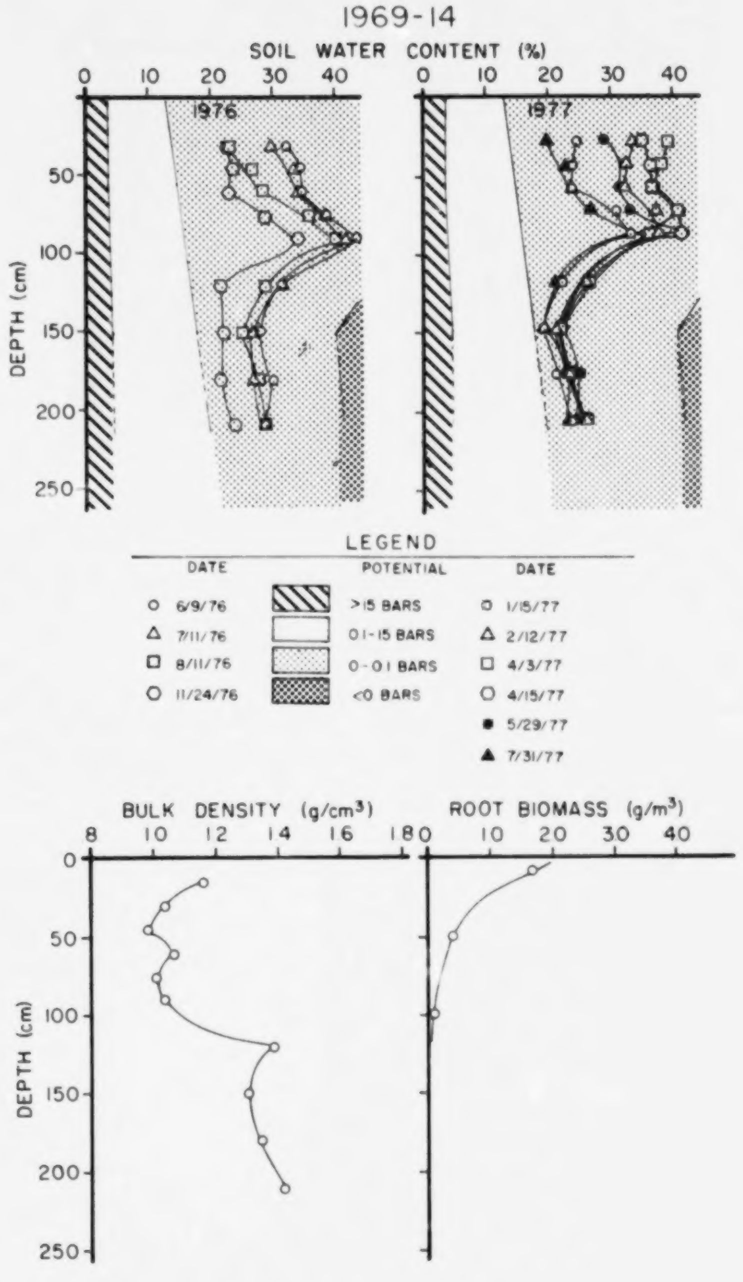


Fig. 52. Seasonal water content, bulk density, and root biomass for the 1969-14 soil.

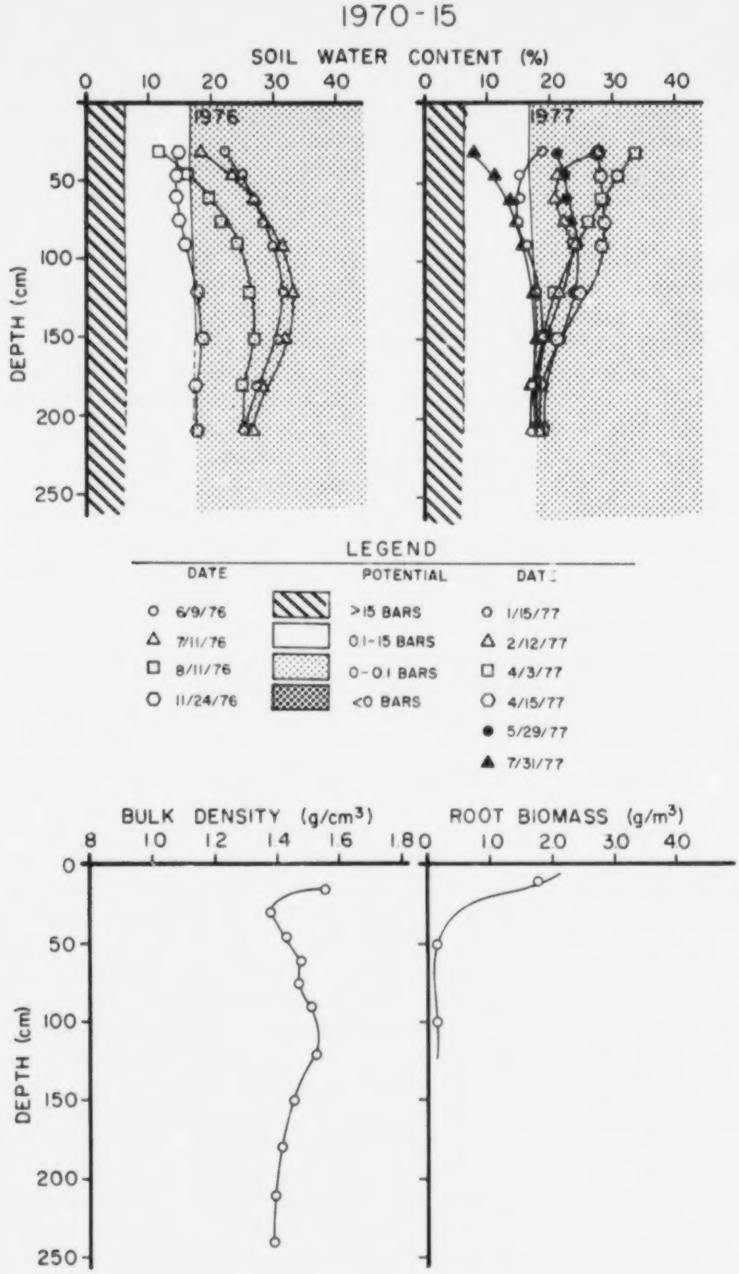


Fig. 53. Seasonal water content, bulk density, and root biomass for the 1970-15 soil.

amounts of water have been used below 100 cm. Since roots extend beyond 100 cm, most plants have access to water even late in the growing season. Few physical restrictions to water movement or root growth occur in natural soils except in the Riedel-6 soil which has a paralithic contact at 50 cm which restricts root growth. On April 3, 1977 a large amount of water was observed in the upper part of the profile. By mid-April the water had drained downward as a wetting front. The depth of penetration of this front represents the depth of recharge. In nearly all natural soils the wetting front moved to 250 cm leaving the profile at field capacity. Some drainage may occur below the root zone in natural soils in late spring.

A small amount of water is withdrawn in early spring from the upper 50 cm of old minesoils , perhaps by annual grasses. During the summer of 1976, water is removed more uniformly from all depths to 150 cm. By late summer, virtually all available water is removed from the root zone. As a consequence of this depletion old minesoils were only recharged to 100 to 120 cm in 1977. Below that depth the soil remained dry. The rapid water use at depths is explained by the dominance of shrubs and half-shrubs on these sites. Root biomass below 50 cm in old minesoils is greater than in natural soils or new mine soils. Very little drainage probably occurs from old mine soils because nearly all water is used by the plant community. The total amount of water used in these soils was slightly greater than in other soils even though they were often sandier and held less water. Site 3 which was leveled in 1948 had higher water contents than most other soils. A large amount of coal was mixed into this profile which resulted in low bulk density. It is possible that water-holding characteristics or the high hydrogen content of the coal caused the unusually high readings. A similar water content curve was found in the 1969-14 site which also contained abundant coal fragments.

The pattern of water use in new minesoils is somewhat similar to natural soils except that water use begins earlier and is more rapid in the spring. Water is removed from progressively deeper depths later in the season. Water use rate slows considerably by mid-summer. During early spring, from April 15 to May 31, 1977; 6.3 cm of water was removed from new minesoils compared to only 4.4 cm in natural soils and 2.9 cm in old mine soils. This early water use is a reflection of the vigorous spring growth of the introduced grasses common on this site. Water use declines in the summer so that use during the entire growing season is slightly less than in natural soils. New minesoils have some plant-available water remaining in the root zone of most plants even in late summer. As a result of the incomplete water use, new minesoils were completely recharged in the spring of 1977. Water is not used from below 100 cm on many of the youngest reclaimed soils. This could be due to the lack of a well-developed root system, or the presence of soil layers which prohibit deep root penetration. The older, well-established plant communities on new minesoils have water use patterns which are similar to natural soils (1972-13, and 1970-15). Water use on very recent minesoils (1975-11) is minimal. It is possible that a large amount of water drains from these soils which could affect the quality and quantity of aquifers developing in the spoils. Unvegetated sites generally have higher run-off rates, however, which may prevent water from draining through the soil.

The total water stored in each soil when recharged was highly correlated with the silt content (r = .73) and sand content (r = -.66) of the soils (Wyatt, 1978). Water content was therefore highly influenced by soil texture. Water use at 50 and 100 cm from April 4 to June 15, 1977 was most highly correlated with root biomass. Water use and root biomass were not correlated at the 10 cm depth perhaps because other factors such as surface evaporation also influence water movement in this zone (Table 12). Water use was not well correlated with root biomass in old minesoils. This could have occurred because most root weight at 50 cm and 100 cm in these soils consists of large taproots which are not as effective in absorbing water. Water use at these depths in the old minesoils occurred primarily after June 15 also.

Table 12. Correlation (r) between root biomass (g/cm^3) and water use (cm^3/cm^3) from 4/4/77 to 6/15/77 at three depths in natural soils; old, and new mine soils.

Soil Type	Depth (cm)		
	10	50	100
Natural Soils	.45	.98*	.97*
Old Minesoils	-.84	-.73	-.80
New Minesoils	-.75	.99*	.93*

*denotes a significant correlation at p < .95

Soil water is an important factor in the classification of soils (Soil Survey Staff, 1975). Soil moisture regimes have been defined to account for the influence of water on soil genesis and soil use. Based on information collected in this study, soils in the Colstrip region are in an ustic soil moisture regime but border on an aridic regime. These soils would not be dry enough to be classified as Aridisols since they would have to be dry from 20-60 cm for more than one-half the time the soil temperature is above 5°C at 50 cm. For this to occur, the soils would need to be dry at 60 cm by late June and remain dry until December. Soils in this study were not dry at this depth until August and often were re-wetted in October or November. The soils would qualify for aridic subgroups of Mollisols and Inceptisols.

Productivity of all sites was compared to water use and growing season precipitation to evaluate the water use efficiency of vegetation (Table 13). Perennial grass biomass, annual grass biomass, and total biomass were correlated with growing season water use and summer precipitation using multiple linear regression techniques. The magnitude of the coefficient for stored soil water and precipitation indicate the efficiency with which water from that source was used. For example, a coefficient of 42.0 for stored soil water in predicting total biomass means that for each cm of soil water used, 42 kg/ha of vegetation was produced. It was found that stored soil water was more efficient than summer precipitation in producing plant material. This is a common finding as summer rainfall typically is lost by interception and surface evaporation before it can be used by plants.

Table 13. Vegetative production (kg/ha) in 1976 and 1977 was predicted from the amount of stored soil water (cm) depleted from the upper 150 cm, and summer precipitation (cm) using multiple linear regression. The magnitude of each coefficient for soil water and precipitation indicates the efficiency with which that water was used in producing biomass.

PREDICTED COMPONENT	INTERCEPT kg/ha	COEFFICIENTS		R^2	n
		Soil H_2O	PPT		
TOTAL BIOMASS					
ALL SITES	696	42.0	9.6	.27	20
NATIVE	152	51.4	16.4	.24	4
OLD SPOIL	536	81.7	-15.8	.64	5
NEW SPOIL	1409	16.0	-31.0	.24	6
PERENNIAL GRASSES					
ALL SITES	140	27.2	13.0	.19	20
NATIVE	-453	50.7	35.2	.82	4
OLD SPOIL	-613	19.5	91.6	.19	5
NEW SPOIL	1437	4.8	-55.0	.73	6
ANNUAL GRASSES					
ALL SITES	271	2.9	-16.0	.13	20
NATIVE	-533	44.0	5.9	.47	4
OLD SPOIL	203	14.8	-23.1	.31	5
NEW SPOIL	217	7.2	-22.0	.25	6

Water was used most efficiently by old minesoils in producing total biomass which consisted mostly of half-shrubs and annual grasses. However, more perennial grass biomass was produced per unit of water used on natural soils. Total biomass and perennial grass production on new minesoils did not vary much with differences in water use and precipitation in 1976 and 1977. Since many new minesoils are not fully depleted of water during the growing season, water availability may not be the most critical factor in determining productivity. Plant communities on natural soils used summer precipitation more efficiently than either old or new minesoils. Summer precipitation did not, in fact, increase minesoil productivity at all. This difference in use of summer precipitation can be explained by the composition of the plant communities on each site. Both warm- and cool-season grasses and forbs are common on native soils. Some plants are active during all parts of the growing season to utilize water. By contrast, very few warm-season species existed on the new mine soils. Most plants had therefore senesced by the time the summer rain fell. The only active plants on old minesoils during most of the summer were deep-rooted half-shrubs and shrubs. These plants obtained their water primarily below 50 cm during this period and thus could not use summer precipitation which remained in the uppermost soil layers.

Soil Water Potential

Water potential readings obtained with the thermocouple psychrometers (TCP) did not correlate with the changes in water content observed with the neutron probe, and thus were considered inaccurate. Soil water potential data will not be formally discussed in this report. Considerable care must be taken when installing and reading TCP's to avoid temperature gradients in either the TCP or the microvoltmeter used for reading.

The desorption characteristics of each soil were measured by analyzing cores from the neutron access holes, and undisturbed soil clods from a backhoe pit. Soil water content of these samples was measured after equilibrating at 0, 0.1, 0.3, and 15 bars. These data were used to indicate zones of water availability on the soil water content figures (Figures 39 to 53). Water retention at 0.3 and 15 bars were positively correlated with silt content and inversely correlated with sand content. Natural soils held slightly greater water content than minesoils at these potentials because of their lower sand and higher silt and clay content. The water-holding capacity of natural soils were slightly higher than minesoils .

Soil Temperature

Soil temperature at 15, 50, 90 and 150 cm was measured monthly from June, 1976 to August, 1977 (Table B-4). Sensor units were removed from the field for calibration and cleaning during the winter of 1976-1977.

Mean annual soil temperature (MAST) at 50 cm is used in the definition of soil temperature regimes in the soil taxonomy (Soil Survey Staff, 1975). To calculate the MAST, temperature on July 1, October 1, January 1, and April 1 were graphically inferred from a plot of soil temperature data. The average of these dates gives the MAST. All soils in this study had mesic soil temperature regimes or MAST greater than 8°C. Some of the soils on north aspects which remained wetter through much of the year were borderline on a frigid temperature regime (MAST < 8°C).

Old minesoils had somewhat higher soil temperatures than native soils while new minesoils had lower temperatures (Table 14). Old minesoils are drier than other soils because plants use water most fully on these sites. Since water has a large heat capacity, a drier soil would be expected to become warmer than a wet soil. A large litter layer which was observed on new minesoils could account for the lower soil temperature on these soils. Soil temperature at 50 cm in new mine soils showed less seasonal fluctuation than in other soils. This could also be accounted for by the litter layer.

Table 14. Soil temperatures at 50 cm in spring, summer, fall, and winter were graphically inferred from a plot of all soil temperature data. Mean annual soil temperature was calculated from the mean of seasonal temperatures.

		Date					Largest
		7/1/75	10/1/76	1/1/77	4/1/77	Mean Ann.	change in
	Site	Soil Temperature(C°)				Soil (C°) Temp.	(C°) Temp.
Natural soils	Chinook-1	18	13	-2	6	8.75	20
	Boxwell-2	16	15	0	6	9.25	16
	Chinook-8	19	17	0	7	10.75	19
	All					9.6	18.3
Old mine soils	1928-7	19	14	0	6	9.75	19
	1928-9	18	16	0	7	10.25	18
	1929-10	18	15	-.5	7	9.9	18.5
	All					10.0	18.5
New mine soils	1975-11	16	14	0	7	9.25	16
	1973-12	16	10.5	.5	8	8.75	15.5
	1972-13	14	12	2	5	8.75	12
	1970-15	15	14	2	7	9.5	13
	All					8.9	14.1

SECTION 9

ROOT CHARACTERISTICS

A field root counting method which can be used to obtain root biomass was used to characterize roots in the field (Schafer and Nielsen, 1978). Natural soils, old minesoils, and new minesoils differed in total root biomass, root distribution with depths and the size of roots.

Root Biomass

Old minesoils had nearly twice as many roots as natural soils (Table 15). Biomass in the upper 100 cm averaged 743 g/m^2 which was slightly less than in Colorado grasslands (Bartos and Sims, 1974). New minesoils had less roots than natural soils. It appears that either several years are required for mature grassland root systems to develop, or that introduced grasses do not produce as much root biomass as native vegetation.

Table 15. Root biomass, the proportion of roots in surface horizons, and the fraction of roots in various size classes is shown for natural soils and minesoils. Values are the mean of 5 sites.

Soil	Biomass g/m^2	Percent in Upper 25cm	Root Size (min) .1-.5	.5-1	1-2	2-5	>5
					%		
Natural	404	71	32	44	4	20	0
Old	743	63	18	22	22	29	10
New	318	83	34	33	19	7	7

Roots in the upper 25 cm made up 71% of the biomass in native soils and 83% in new minesoils, which were dominated by perennial grasses. Many of the youngest minesoils had over 90% of their roots above 25 cm which suggests that shallow roots develop first in reclaimed plant communities. By contrast only 63% of the roots in old minesoils occurred above 25 cm. This is a reflection of the half-shrub and shrub-dominated plant community. The abundance of deep roots in old minesoils explains the more complete use of water below 50 cm.

The size of roots in natural soils and new minesoils was similar. More than 75% of the root biomass consisted of fine and very fine roots (< 1 mm diameter). Fine (1-2 mm)or medium-sized roots (2-5 mm) made up the remainder of the root weight. Old minesoils had more medium and coarse roots (>2 mm) as a result of the abundance of taproots from *Artemesia dracunculus* and other shrubs. Only 40% by weight of the roots in old minesoils were very fine and fine. Since large roots are less effective in water uptake and have less length per unit weight, roots in old minesoils were probably less efficient per unit weight in taking up water than the more fibrous roots of perennial grasses. More root weight is maintained in deep-rooted plant communities, but water uptake per unit weight of roots is less than in communities with shallow fibrous roots. Deep-rooting provides the advantage of a larger soil water reservoir but exists at the expense of aboveground production since a larger fraction of the photosynthate must be used in the growth and maintenance of the root system.

P^{32} Uptake

Radioactive phosphorus was injected at various soil depths. Vegetation growing above each injection site was monitored for uptake of phosphorus. If P^{32} was found in the plant top, it was assumed that roots were growing at that injection depth. Shielding of the injection device prevented comtamination of sides of the hole when P^{32} was placed in the soil. The absolute amount of P^{32} taken up by the plant top was used as an index of root activity. Corrections were made for P^{32} decay and residual P^{32} from earlier measurement dates using an equation derived in Appendix C. The absolute amount of P^{32} uptake was probably influenced not only by root activity but also by phosphorus availability, and solute transport mechanisms within the plant.

Radioautographs from two plants which had taken up P^{32} were obtained (Fig. 54). The radioactivity was most concentrated in the young, actively growing portions of the plants which in *Artemisia frigida* is at the meristematic tip of young stems, and is near the ground level in *Stipa comata*. Some P^{32} was also found in older stems and leaves, but was less concentrated. Comparison of radioactivity in grasses, forbs, and shrubs is complicated by this differential pattern of phosphorus accumulation. All readings were taken on the most radioactive portion of each plant.

Some natural background levels of beta radiation exist in the environment. Several plants outside the study area were surveyed for radioactivity. No significant differences in background radioactivity were found in different species or at different sites. A single value of 13 counts per minute (cpm) was used as the background radioactivity level. Only radioactivity above 13 cpm would indicate P^{32} uptake. Most radioactive plants had readings of 100 to 10,000 cmp.

Field radioactivity readings were discussed by Wyatt (1978) and appear in Appendix C. Relative P^{32} uptake between dates of measurement was calculated, and is termed the plant activity index (PAI) because it is a function of root activity, and plant transport of solutes. A summary of plant activity index values by soil depth and plant type is found in Table 16 and Table 17.

One objective of this study was to find the maximum rooting depth of common range plants in the Colstrip area both on undisturbed soils as well as minesoils (Wyatt and others, 1978). Knowledge of the required depth of the

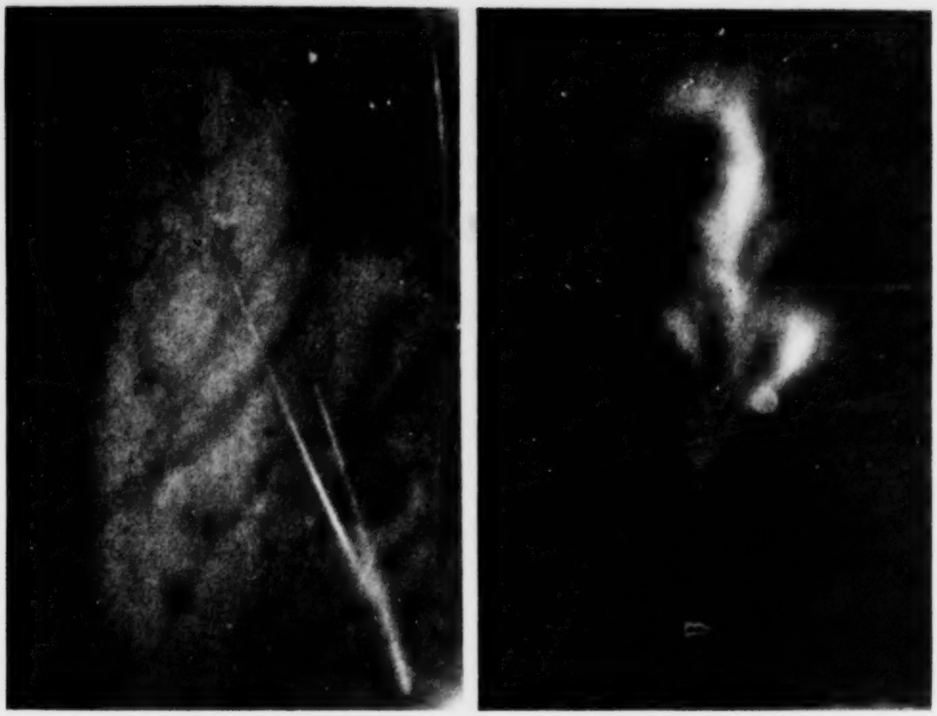


Fig. 54. Radioautographs of a grass (needle-and-thread) and a half-shrub (broom snakeweed) showing P^{32} accumulation in the meristematic regions.

Table 16. Summary of plant activity index (PAI) values for various vegetation types on Colstrip soils during 1975 and 1977.

SOIL TYPE	VEGETATION TYPE	6/27	7/16	8/19	1976	4/17	5/1	5/13	6/15	7/9	7/19	7/31	1977	Both Years
NATURAL SOILS	PERENNIAL GR.	55^{11*}	127^{11}	-69^{11}	38^{33}	94^{7}	46^{8}	82^{10}	47^{24}	136^{28}	301^{28}	136^{17}	144^{122}	121^{155}
	ANNUAL GR.	35^{4}	122^{3}	-25^{1}	60^{8}	-	-	-	-	-	-	-	-	60^{8}
	FORBS	73^{9}	165^{10}	143^{3}	124^{22}	13^{3}	64^{4}	110^{5}	22^{8}	14^{8}	214^{8}	-240^{5}	40^{41}	69^{63}
	SHRUBS	46^{4}	47^{5}	41^{4}	45^{13}	70^{2}	56^{3}	25^{3}	70^{4}	-24^{4}	17^{4}	103^{2}	38^{22}	41^{35}
	ALL	57^{28}	126^{29}	-10^{19}	67^{76}	70^{12}	53^{15}	40^{18}	44^{36}	96^{40}	255^{40}	55^{24}	108^{193}	96^{261}
OLD MINE SOILS	PERENNIAL GR.	8^{3}	7^{5}	1^{3}	6^{11}	7^{5}	6^{7}	43^{11}	105^{13}	-150^{19}	-118^{14}	-24^{4}	-28^{68}	-24^{79}
	ANNUAL GR.	-	-	-	-	-	-	-	-	-	-	-	-	-
	FORBS	10^{5}	23^{10}	9^{6}	16^{21}	11^{1}	102^{2}	206^{3}	25^{1}	-136^{4}	-203^{4}	-71^{2}	-18^{17}	-8^{38}
	SHRUBS	33^{7}	53^{11}	9^{8}	34^{26}	6^{1}	14^{2}	196^{2}	15^{2}	-31^{3}	-12^{9}	-66^{2}	6^{21}	21^{47}
	ALL	20^{15}	33^{26}	8^{17}	22^{58}	7^{7}	30^{9}	93^{16}	89^{16}	130^{21}	-95^{27}	-46^{8}	-23^{106}	-7^{166}
NEW MINE SOILS	PERENNIAL GR.	6^{11}	21^{12}	5^{18}	10^{41}	53^{5}	155^{11}	108^{13}	7^{19}	0^{19}	-126^{20}	-	71^{87}	11^{128}
	ANNUAL GR.	3^{2}	13^{1}	-11^{1}	-3^{4}	-	-	-	-	2^{1}	-106^{1}	-	-52^{2}	-19^{6}
	FORBS	47^{6}	108^{7}	56^{6}	72^{19}	11^{2}	100^{3}	-58^{3}	12^{3}	-42^{3}	-80^{3}	-	-11^{17}	33^{36}
	SHRUBS	-	6^{5}	-4^{3}	2^{8}	-	-	6^{1}	2^{2}	9^{2}	-13^{1}	-	3^{6}	2^{14}
	ALL	19^{19}	42^{25}	13^{28}	25^{72}	41^{7}	143^{14}	73^{17}	7^{26}	-6^{25}	-115^{25}	-	6^{112}	14^{184}
ALL SOILS	PERENNIAL GR.	28^{25}	60^{28}	-21^{32}	20^{85}	56^{17}	81^{26}	79^{34}	47^{56}	28^{61}	69^{62}	106^{21}	60^{217}	51^{362}
	ANNUAL GR.	24^{6}	95^{4}	-28^{2}	39^{12}	-	-	-	-	2^{1}	-106^{1}	-	-52^{2}	26^{14}
	FORBS	49^{20}	98^{27}	54^{15}	72^{62}	12^{6}	140^{9}	90^{11}	20^{12}	37^{15}	58^{15}	-192^{7}	20^{75}	44^{137}
	SHRUBS	38^{11}	40^{21}	15^{15}	32^{67}	48^{3}	39^{5}	79^{6}	19^{8}	-19^{9}	-6^{16}	19^{4}	18^{49}	25^{96}
	ALL	36^{52}	69^{80}	5^{64}	39^{196}	45^{26}	83^{43}	81^{51}	42^{76}	11^{86}	54^{92}	30^{32}	47^{403}	44^{599}

*Superscript represents the number of readings obtained to compute the mean

Table 17. Summary of plant activity index (PAI) values representing P^{32} uptake from various soil depths of Colstrip soils during 1976 and 1977.

	Depth (cm)	6/27	7/16	8/19	1976	4/17	5/1	5/13	6/15	7/9	7/19	7/31	1977	Both Years
NATURAL SOILS	15	92^{5}	179^{7}	-79^{7}	64^{19}	68^{9}	59^{10}	125^{10}	56^{19}	78^{19}	172^{19}	68^{11}	93^{97}	91^{116}
	46	64^{6}	169^{7}	74^{4}	110^{17}	3^{1}	27^{3}	25^{6}	48^{9}	26^{11}	424^{11}	-219^{7}	85^{48}	104^{65}
	76	66^{9}	123^{10}	7^{5}	74^{25}	109^{2}	57^{2}	23^{2}	15^{5}	204^{6}	350^{6}	123^{3}	160^{26}	118^{51}
	107	19^{2}	-4^{2}		8^{4}				12^{2}	416^{2}	1619^{2}	869^{2}	729^{8}	489^{12}
	137	72^{3}	-3^{2}	19^{2}	16^{7}			1^{1}	-2^{1}	-1^{2}	-104^{2}	-1^{1}	-30^{7}	-7^{14}
	183	10^{3}	4^{1}		9^{4}									9^{4}
OLD MINE SOILS	15	35^{5}	43^{6}	-14^{3}	28^{14}	6^{4}	39^{7}	122^{11}	50^{11}	-78^{12}	-135^{12}	-61^{4}	-10^{61}	-3^{75}
	46	19^{5}	57^{4}	20^{2}	33^{11}	8^{3}	0^{4}	27^{5}	184^{5}	-257^{6}	-256^{7}	-40^{3}	-62^{38}	-40^{49}
	76	9^{3}	34^{7}	5^{5}	21^{15}				7^{3}	75^{3}	274^{3}	-6^{1}	108^{10}	56^{25}
	107	5^{2}	26^{4}	-1^{3}	12^{9}									12^{9}
	137		5^{4}	27^{4}	16^{8}									16^{8}
NEW MINE SOILS	15	49^{6}	39^{6}	24^{8}	35^{20}	47^{6}	177^{13}	77^{16}	3^{18}	-13^{18}	-141^{18}		11^{89}	19^{109}
	46	7^{5}	100^{7}	1^{7}	40^{19}				25^{4}	21^{5}	-58^{5}		-6^{14}	20^{33}
	76	2^{5}	16^{6}	10^{5}	7^{16}	3^{1}	-2^{1}	-1^{1}	26^{1}	-11^{1}	-40^{1}		-4^{6}	4^{22}
	107	2^{1}	2^{3}	15^{3}	8^{7}				1^{1}	38^{1}	-15^{1}		-8^{3}	8^{10}
	137	2^{2}	11^{3}	-4^{5}	1^{10}						2^{1}		2^{1}	1^{11}
ALL SOILS	15	58^{16}	92^{19}	-22^{81}	43^{53}	48^{19}	105^{30}	103^{37}	35^{48}	6^{49}	-18^{49}	34^{15}	38^{247}	39^{300}
	46	32^{16}	117^{18}	26^{13}	63^{47}	7^{4}	12^{7}	26^{11}	81^{18}	-52^{22}	112^{23}	-165^{10}	16^{100}	31^{147}
	76	37^{17}	68^{23}	7^{15}	25^{55}	74^{3}	37^{3}	15^{3}	14^{9}	144^{10}	428^{10}	91^{4}	124^{42}	68^{97}
	107	10^{5}	11^{9}	7^{6}	10^{20}				8^{3}	290^{3}	1074^{3}	869^{2}	532^{11}	195^{31}
	137	17^{5}	5^{9}	11^{11}	10^{25}			1^{1}	-2^{1}	-1^{2}	-69^{3}	-1^{1}	-26^{8}	1^{33}
	183	10^{3}	4^{1}		4^{4}									4^{4}

*superscript represents the number of readings obtained to compute the mean.

root zone is important in mine reclamation so that potentially phytotoxic overburden materials, saline materials, and physical barriers to root growth can be eliminated from that depth. The maximum observed rooting depth of 41 species which took up phosphorus is shown in Table 18. These data are based on a limited number of injections of small spatial extent. The values reported do not necessarily represent the maximum rooting depth except for the most common species. These are minimum estimates. Plant roots of many perennial grasses, forbs, and shrubs extend to at least 137 cm on natural soils, old minesoils, and new minesoils . *Stipa comata* had roots at least as deep as 183 cm on native soils. Plants on all sites can probably obtain water or nutrients from the upper 150 to 200 cm of soil at all sites.

An analysis of variance was conducted on P^{32} uptake data from 1976 (Table 19). Significant differences in uptake occurred between groups, dates of measurements, and depth of uptake. In addition, the group by date interaction and group by depth interaction were also significant which indicates that the pattern of change of P^{32} uptake on successive dates and with increasing depth was different for natural soils and minesoils . These patterns will be discussed in detail in the following sections. The date by depth interaction was also significant.

The average plant activity index on each measurement date for each soil is shown in Table 20. These are the average of all species at all depths which took up phosphorus. The average PAI is greatest for native soils in both 1976 and 1977, and on 6 out of the 10 measurement dates during the study. The smaller PAI in minesoils could be caused by 1) less root biomass,

Table 18. Maximum observed rooting depths using P^{32} tracer in Colstrip soils.

	Rooting Depth (cm)		
Species	Native Soil	Old Spoil	New Spoil
Grass			
Agropyron cristatum			76
Agropyron dasystachyum			46
Agropyron elongatum			137
Agropyron smithii	46	107	15
Agropyron spicatum		76	
Agropyron trachycaulum		107	137
Agropyron tricophorum		46	
Avena fatua			46
Bouteloua gracilis	76		
Bromus inermis			76
Bromus tectorum	76		
Calamovilfa longifolia	46		
Koeleria cristatum	76	76	
Poa pratensis		46	
Poa sandbergii	46		
Stipa comata	183	137	
Forb			
Agroseris glauca		107	
Ambrosia psilostachya	76	137	
Astragalus cicer		15	
Calochortus nuttallii	15		
Gaura coccinea	137		
Grindelia squamosa		15	
Lactuca pulchoha		107	
Lactuca serriola		46	
Leucorcrinum montanum	46		
Melilotus officinalis	137	137	15
Medicago sativa			76
Petalostemon purpureum	76	15	
Psoralea esculenta	76	76	
Salsola kali			46
Tragopogon dubius	137	46	
Shrub			
Ankanaria species	15		
Artemisia cana		15	
Artemisia dracunculus	137	137	
Artemisia frigida	46	15	
Artemisia ludoviciana		76	
Chrysopsis villosa	46	46	
Chrysothamnus nauseosus	15		
Chrysothamnus viscidiflorus			107
Gutierriza sarothrae		64	
Rosa species		15	

Table 19. Analysis of variance fo P^{32} uptake (counts/minute) showing sources of variation for the 1976 growing season.

SOURCE	DF	SS	MS	F	P
GROUP	2	2336349	1168174	15.47	< .001
DATE	3	1193790	596895	7.90	.003
DEPTH	5	4554351	910870	12.06	< .001
GRP X DATE	4	840044	210011	2.78	.055
GRP X DEPTH	10	2926526	292652	3.88	.005
DATE X DEPTH	10	1981030	198103	2.62	.032
ERROR	20	1510317	75516		
TOTAL	53	15343410	289479		

Table 20. Average plant activity index (PAI) values from all species and all soil depths is shown for the 1976 and 1976 growing seasons on Colstrip soils.

	1976			1977							Average		
Soil type	6/27	7/16	8/19	4/17	5/1	5/13	6/15	7/9	7/19	7/31	1976	1977	Both
Native Soils	57	126	-10	70	53	40	44	96	255	55	67	108	96
Old Mine Soils	20	33	8	7	30	93	89	-130	-95	-46	22	-23	-7
New Mine Soils	19	42	13	41	143	73	7	-4	-115		25	6	14

2) less affinity for phosphorus, 3) phenological differences in plants within each community, or 4) less availability of added P^{32}. Old minesoils have nearly twice as much root biomass as natural soils, and identical species growing on natural soils and minesoils reflect the same relative differences in PAI. Differences in PAI are probably therefore due to differences in phenology and P^{32} availability. Plant communities on new minesoils cease to take up P^{32} by mid-June in 1977. Water use was also observed to decrease during this period, probably because of initiation of summer-dormancy in the introduced perennial grasses dominant on new minesoils. The activity of surface roots ceased by late June in old minesoils even though deep roots continued to take up P^{32}. Roots at all depths in natural soils continued to take up P^{32} through July. These phenological patterns account in part for differences in the PAI. Minesoils have a slightly higher pH than natural soils and contain up to 10% $CaCO_3$ while most natural soils are free of $CaCO_3$ in the upper 50 cm. Phosphorus can precipitate on $CaCO_3$ surfaces and is rendered unavailable to plants in the process. In addition, phosphorus availability to plants tends to decrease with increases in pH between 7.5 and 8.5. Soil factors which influence phosphorus availability probably also affect the PAI values in these soils.

Comparisons of PAI between 1976 and 1977 must be made with care since injections were made at different times of the year. Qualitative comparisons are valid, however. The main difference between the two years is in the depth of P^{32} uptake (Table 18). Uptake occurred from deeper depths in larger amounts in 1976 than 1977. This occurrence can be explained by precipitation patterns. A wet spring in 1976 caused soil water to be recharged throughout the root zone while a dry summer required plants to obtain water from deep in the soil. Soils were not as fully recharged during the dry spring of 1977, and higher than normal precipitation during the summer provided much additional water near the soil surface. Plant communities apparently have the capacity to respond to climatic fluctuations by increasing root activity where water is most available. As a result, marked differences in root growth probably occur from year to year.

Increases in the PAI of plants should indicate increases in root activity. A value of zero indicates no uptake of P^{32} and thus no root activity. Many negative values of PAI were found, however. Plant activity index below zero does not agree with the simplified interpretation of PAI values originally assumed. Other factors must influence PAI. Sosebee and Wiebe (1973) studied the movement of foliar-applied P^{32} in crested wheatgrass *(Agropyron cristatum)*. They found that as plants approached summer dormancy in August, P^{32} in leaves, internodes, and the inflorescence decreased to near zero. At the same time, the radioactivity of the crown and plant roots increased to a maximum level. The same flux of materials into the root system late in the growing season was indicated by Ares and Singh (1974) in their model of the dynamics of a shortgrass root system. Therefore, PAI reflects the balance of upward movement of P^{32} from active roots, and downward movement of previously assimilated P^{32} into roots and crowns for storage. When downward transport exceeds uptake, negative values for PAI are obtained, which indicates that plant senescence is approaching.

Perennial grasses on natural soils remain active throughout the April to August growing season in 1977 (Fig. 55). Peak PAI values occurred in mid-July which was two weeks after several cm of rain fell in the area. Perennial grasses on old and new spoils had peak PAI values earlier in the growing season while senescence occurred as early as late June or early July. The maximum plant activity index on new minesoils occurred in early May when introduced grasses on the spoils were greening up. Forbs show the same PAI pattern as perennial grasses except that senescence occurred about two weeks earliers on all sites. Shrub root activity was less than either grasses or forbs probably because the taproot system has fewer numbers of roots in a volume of soil than do fibrous-rooted grasses.

The depth of active roots in natural soils; old and new minesoils is shown in Fig. 56. Old and new minesoils follow a similar pattern. Root activity at 15 cm begins early but ceases by late June when water has been depleted and senescence is approaching. Peak root activity at 15 cm in new minesoils , old minesoils, and natural soils occurred in late April, mid-May, and mid-July respectively. As a consequence of senescence of plants on minesoils , the abundant summer precipitation during 1977 could not be used for additional growth. A similar pattern of root growth occurs at 45 cm except that plant activity peaks later in the season. Plants on old mine soils take up more P^{32} than plants on new minesoils at this and deeper depths probably due to higher root biomass. Minesoils rely almost entirely on root activity below 50 cm during June and part of July when the plants are approaching maturity. Although uptake of P^{32} at 15 cm continues in natural soils through July, an increasing proportion of the total uptake comes from deep soil depths. Although roots below 50 cm comprise less than 10% of the total root biomass, these deep roots are critical in supplying water and

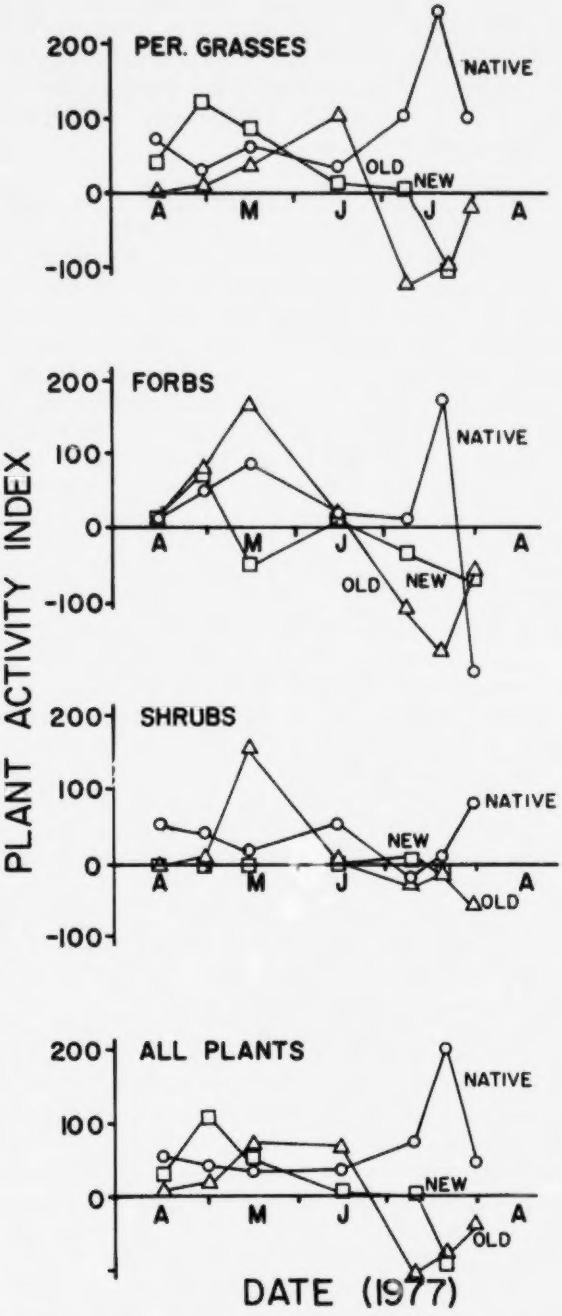


Fig. 55. Average plant activity index for various vegetative types through the 1977 growing season.

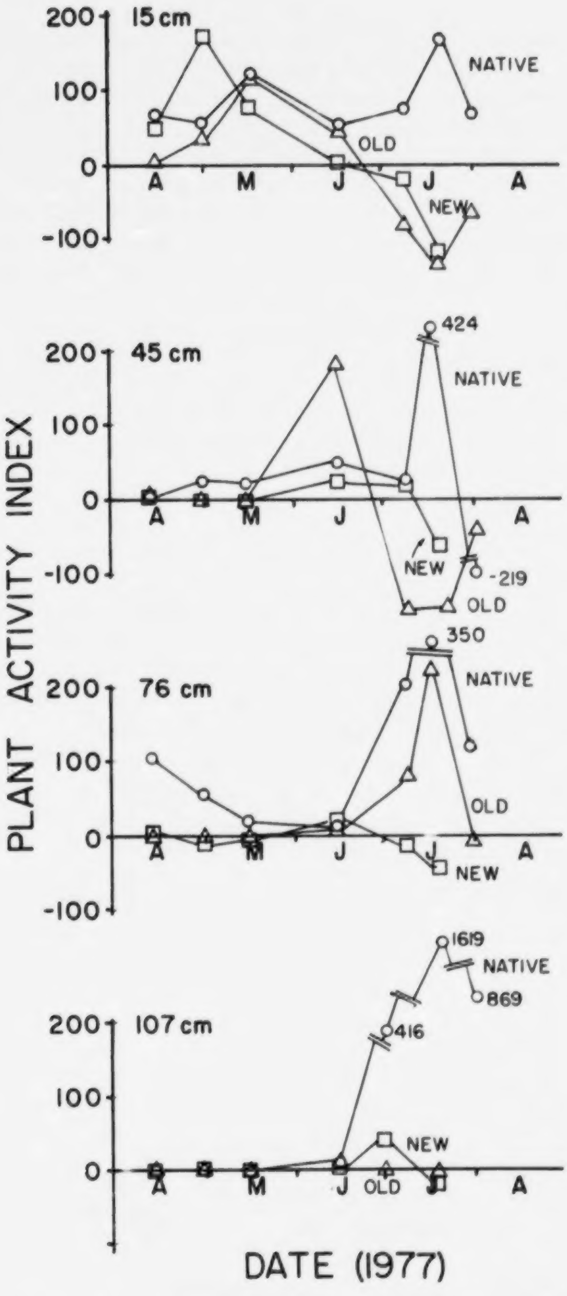


Fig. 56. Average plant activity index for uptake from several soil depths through the 1977 growing season.

nutrients to plants late in the growing season.

To better understand the processes in soil that influence root growth and plant senescence, and how individual species respond to environmental changes; plant activity index of several species was compared to soil temperature and soil water content in an undisturbed soil (Fig. 57). It appears that root growth initiates at deeper depths as the growing season progresses. The date of initiation corresponds closely to the movement of the 11 to 14°C isotherm as the soil warms. Uptake of P^{32} by root growth becomes less than downward transport when PAI falls below zero. This decrease in PAI occurs when the soil dries to near the permanent wilting point. Since the soil at deeper depths did not dry to 15 bars during the observation period, PAI remained positive. *Stipa comata* which has a dense, fibrous root system, exhibits the highest PAI values perhaps because it has more roots in contact with the injected P^{32}. The initiation of growth of *Stipa comata, Koeleria cristata, Tragopogon dubius,* and *Artemesia frigida* was nearly the same at each soil depth. *Bouteloua gracilis,* a warm-season grass, appeared to begin growth slightly later than other species.

Soil temperature appears to control the initiation of growth in these soils. New minesoils have slightly lower soil temperatures and warm more slowly in the spring than other soils, perhaps due to large litter accumulations and wetter soils. It takes nearly two weeks longer for new minesoils to reach 11 to 14 C° at any depth than other soils because these soils are wetter and have thick litter layers. Limited water availability influences the length of time roots can remain functional. When the water potential nears 15 bars, most root activity ceases. Sandy soils with less water-holding capacity such as the old minesoils dry out sooner than other soils. As a result, droughty soils have a shorter effective growing season. Genetic differences between plant species cause plants to respond differently to changes in the soil environment. Plants adapted to dry climates or short growing seasons will begin growth earlier or sustain it later than poorly adapted plants under similar soil temperature and water availability. Plant ecotypes adapted or bred for the soils and climate of a particular region should be most successful in establishment of self-sustaining reclaimed plant communities.

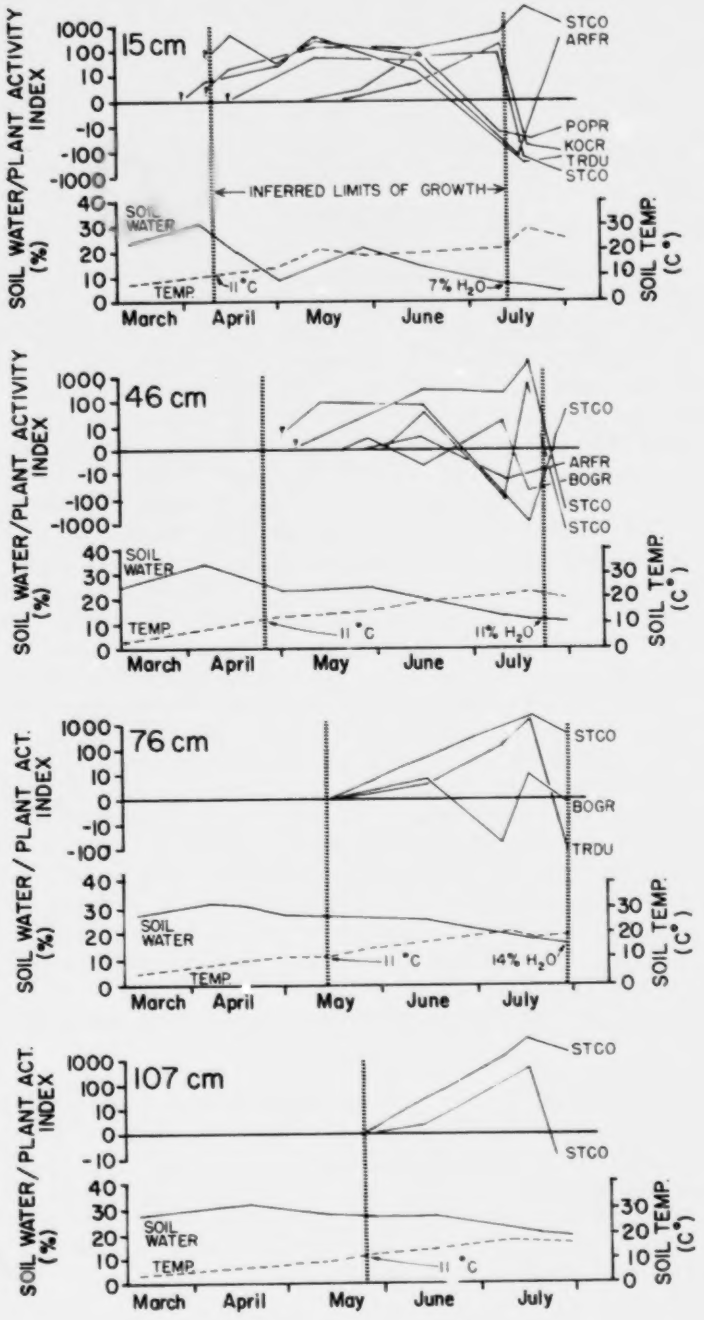


Fig. 57. Plant activity index of several species at the Chinook-1 site is shown in relation to season changes in soil temperature and water content at several depths.

SECTION 10

MICROBIOLOGICAL ACTIVITY

Adenosine triphosphate (ATP) is an essential part of all living cells. The ATP content of microorganisms remains constant throughout all life stages and ATP quickly disintegrates after the death of a cell. Measurement of ATP activity in soils is, therefore, an excellent index of microbiological activity in the soil. Maximum ATP concentration in samples collected during August, 1976 varied from 10^7 to 10^9 fg/g in the 15 soils studied (Figs. 58-60). The relative distribution of ATP with depth was similar in all soils. Maximum ATP content occurred in the top 1 cm in most cases. Adenosine triphosphate concentration decreased rapidly with depth until equilibrium levels of 1×10^7 to 5×10^7 fg/g were reached at about 50 cm in natural soils and 30 cm in minesoils. Differences were not apparent between maximum ATP activity in natural soils and minesoils. Natural soils generally had higher ATP activity than minesoils from 10 to 50 cm, however. It appeared from the pattern of ATP distribution with depth that microbiological activity was not strongly influenced by differences in water content. When samples were taken in August, 1976, a dry summer, soils were dry throughout most of the root zone, but were moist below 100 to 150 cm. Microbiological activity was probably more influenced by the availability of food (organic carbon) and nutrients than by water. Organic carbon content of all soils was highest near the surface and decreased with depth which paralleled the distribution of ATP. Natural soils had more organic carbon than minesoils from 10-50 cm which may explain the differences in ATP activity at these depth. It is interesting to note that relative differences in ATP activity between mine soils and natural soils were not as large as differences in organic carbon content. Although less organic carbon occurred in minesoils, ATP activity was nearly the same which suggests that the organic matter in minesoils is less decomposed (and thus yields more energy) than organic matter in natural soils.

The distribution of ATP in the 1975-11 site, the youngest minesoil, differed from the pattern described above. Maximum ATP concentration was only about 5×10^7 fg/g and occurred at 20cm rather than near the soil surface. This difference in ATP distribution is probably a result of the youth of this site. A comparison of the 1973-12, 1972-13, and 1970-15 sites indicates that ATP distribution in minesoils becomes more similar to the pattern found in natural soils with increasing age.

The 1948-3 site and the 1969-14 site each had very low maximum ATP levels. These two soils are unique in the study in that each contained a large volume of coal fragments. The 1948-3 site in particular had fine coal particles distributed throughout the soil matrix. It is possible that coal inhibits microorganism populations in some way.

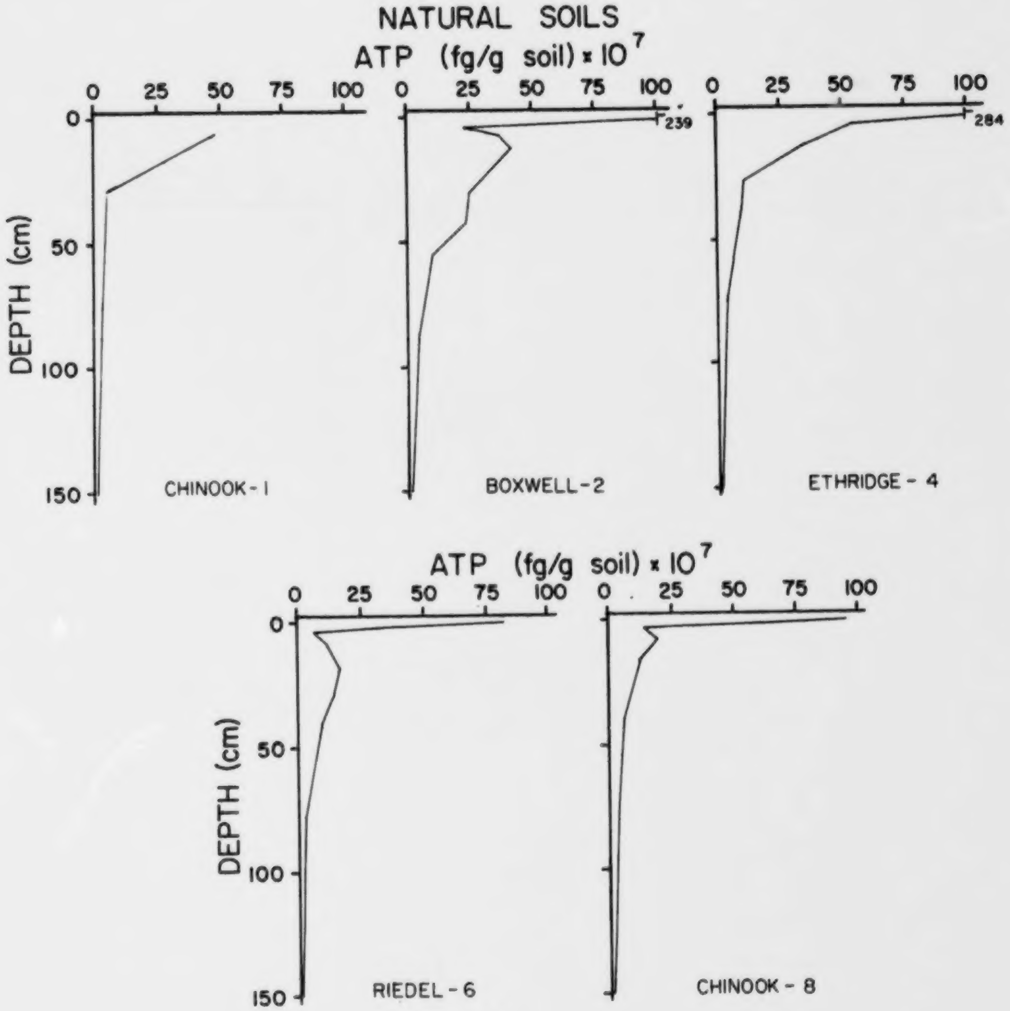


Fig. 58. ATP activity in natural soils, August, 1976.

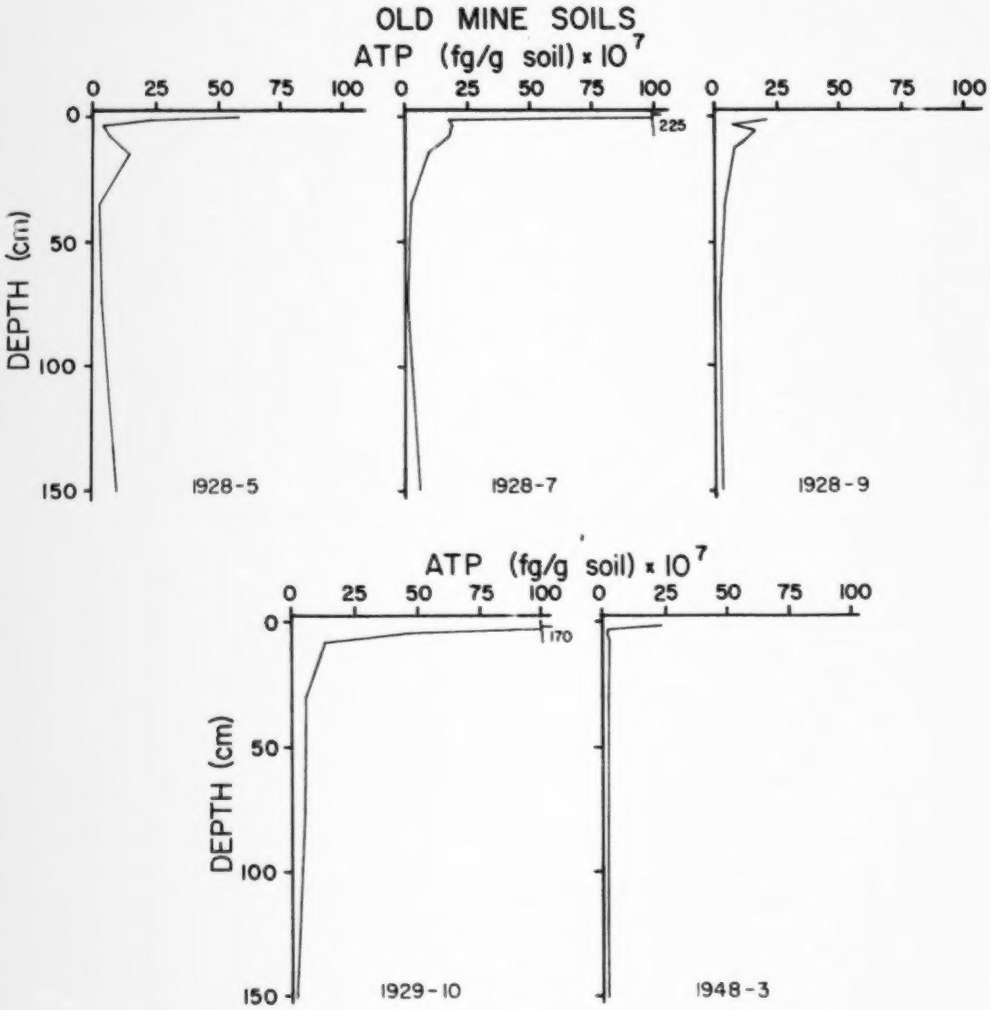


Fig. 59. ATP activity in old minesoils, August, 1976.

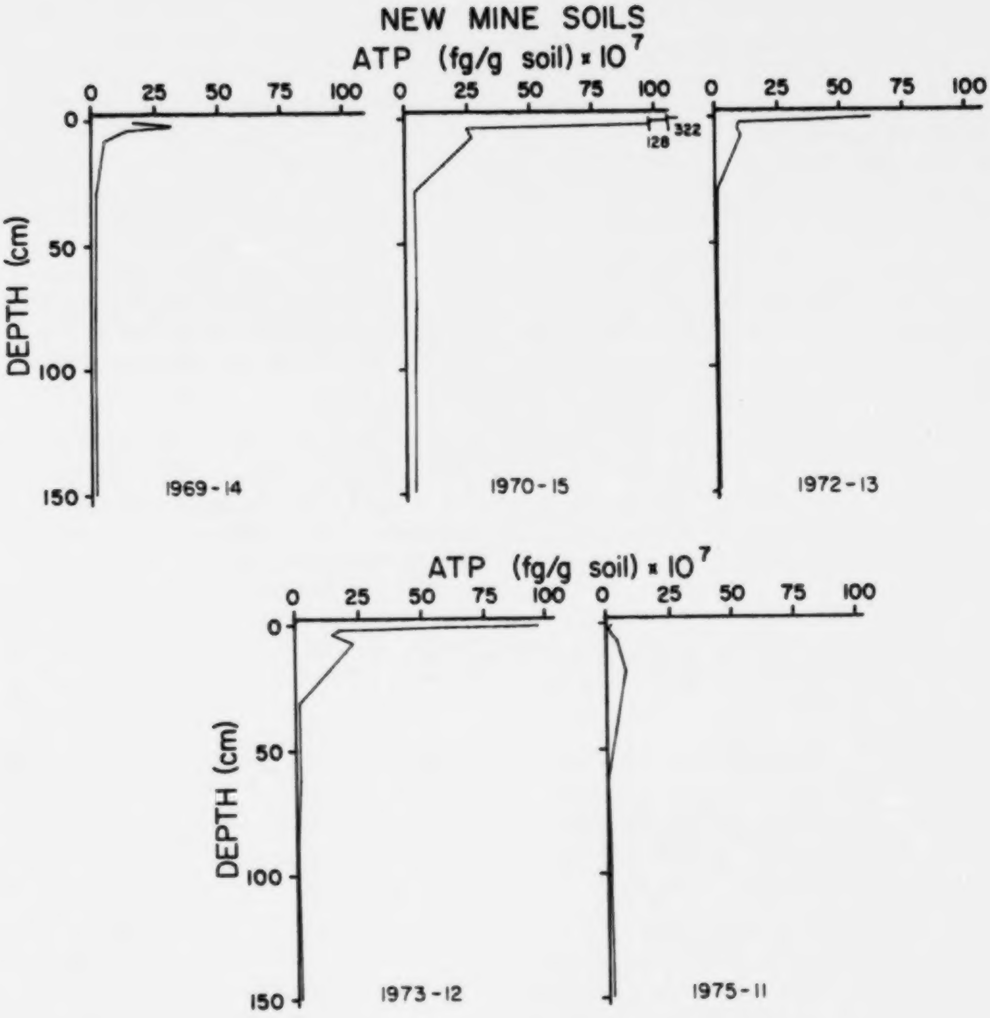


Fig. 60. ATP activity in new minesoils, August, 1976.

Selected soils were analyzed for ATP content again in June, 1977 (Fig. 61). Samples were collected every 10 cm to 30 cm in depth so that caution is needed in making direct comparisons between June, 1977 and August, 1976 ATP activities. No apparent differences existed between ATP concentration in natural soils and minesoils . It is interesting, however, that three of the five soils studied had maximum ATP levels at 30 cm rather than near the soil surface. In addition, ATP activity at 20 and 30 cm was higher in these samples than in August, 1976. Higher ATP levels could have been caused by increased nutrient or food availability. This agrees with the findings of Bartos and Jameson (1974) who found that root decomposition rate reached a maximum in early summer in Colorado grasslands. Haigh (1976) recorded the highest yearly soil nitrate levels during June in several Montana soils.

Large differences in ATP activity were found for the three minesoils deposited in 1928 (1928-5, 1928-7, and 1928-9). These soils are edaphically very similar. These relative differences in ATP activity were often reversed on other sampling dates which suggests that ATP activity is an extremely variable property.

Adenosine triphosphate activity was measured again in October, 1977 on five selected soils. No differences between natural soils, old and new mine soils were apparent (Fig. 62). Maximum ATP concentration again occurred near the soil surface as in the August, 1976 samples. The average ATP activity in the upper 30 cm of these soils was the highest measured in the study. It is possible that increased nutrient availability, or increased water content accounted for the higher ATP levels. Weaver and Forcella (1978) found that maximum annual levels of available phosphorus, ammonium, and potassium occurred in September or October under six vegetation types in western Montana.

Conditions may be most favorable for microbiological activity both early and late in the growing season when nutrients, soil water, and food sources (dead roots) are at a maximum. During the winter, soil temperature is too low for maximum growth while during the midsummer, grasses, forbs, and shrubs may compete effectively for limited water and nutrients.

Rhizosphere, rhizoplane, and free-soil ATP activity values are shown for 14 plant species in Table 21. The rhizoplane is the root surface, the rhizosphere is the soil zone surrounding the root, while free soil is material not in close contact with plant roots. Microbiological activity was highest in the rhizoplane for all 14 plant species analyzed. Rhizoplane ATP levels ranged from $9\text{x}10^8$ to $215\text{x}10^8$ fg/g. Rhizosphere ATP activity was slightly higher than free soil activity for 8 of 14 plants. Even though rhizoplane ATP activity was higher than either rhizosphere or free soil levels, ATP in the rhizoplane comprised only a small portion of the total ATP in each sample. This occurred because only about 1% of each sample was in the rhizoplane zone.

Free soil, and rhizophere ATP activity were exceptionally low in the 1948-3 site. For these samples, the majority of the ATP in the sample was found in the rhizoplane even though only 0.5 to 3.2% of the sample was rhizoplane material. As suggested in an earlier section, it is possible that

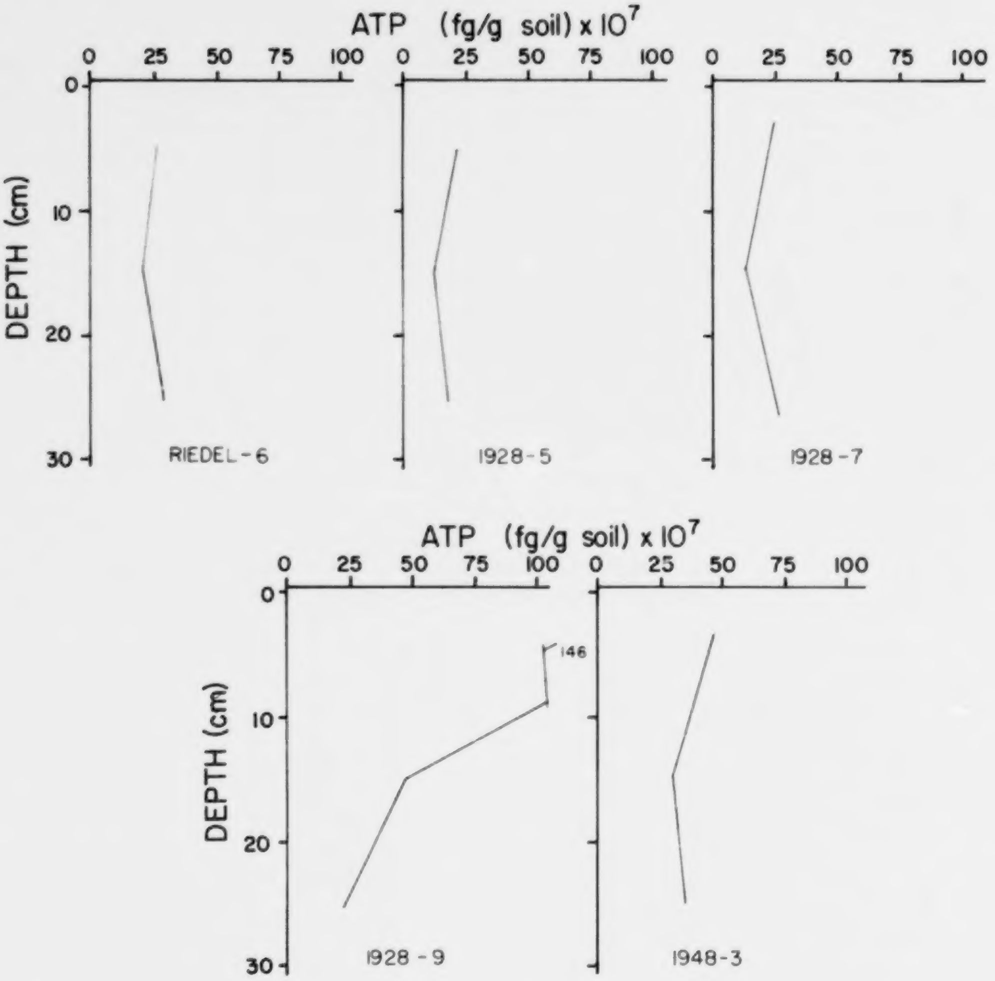


Fig. 61. ATP activity in selected soils, June, 1977.

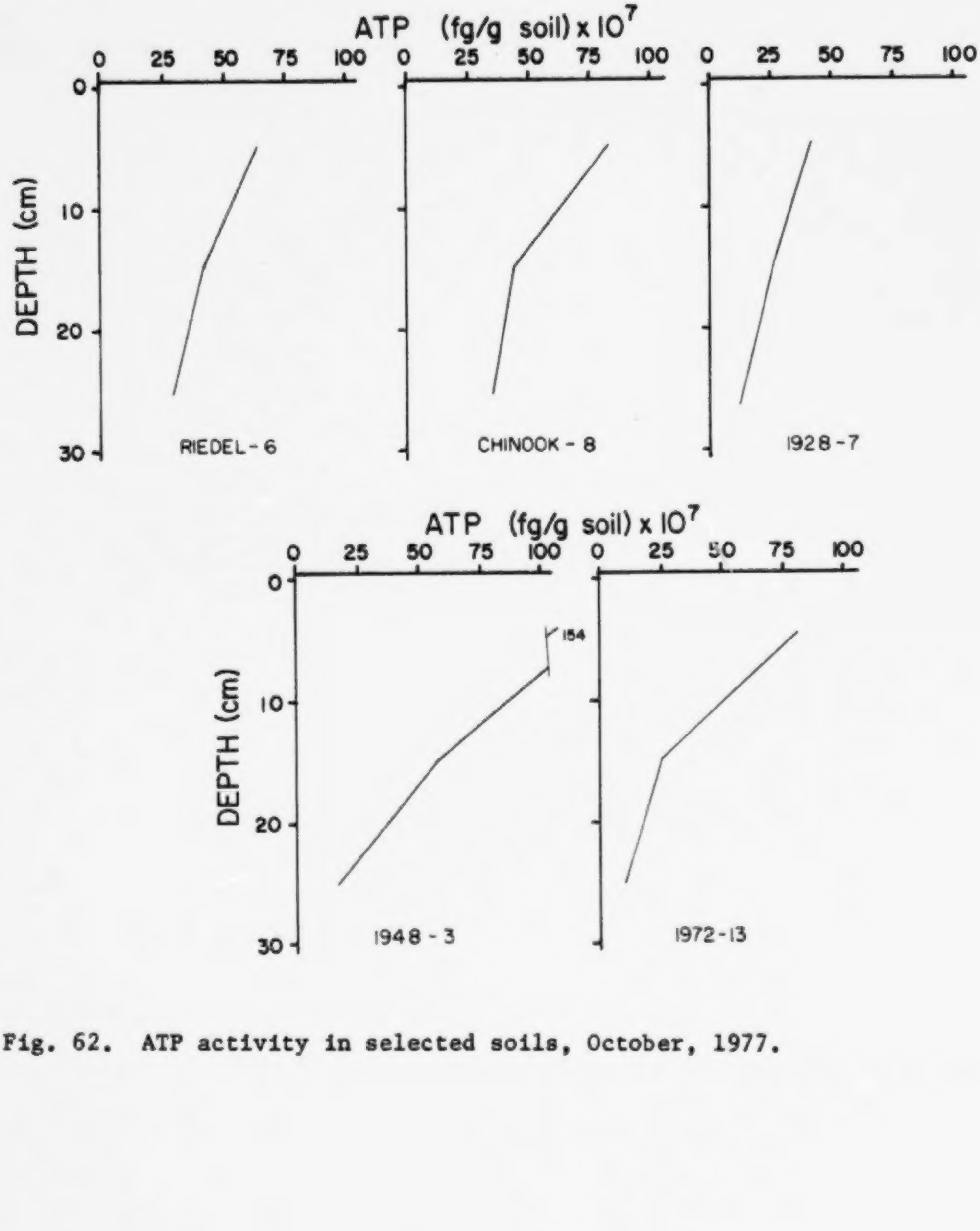


Fig. 62. ATP activity in selected soils, October, 1977.

Table 21. ATP in free soil, rhizopshere and rhizoplane

Site		Free Soil		Rhizosphere Soil		Rhizoplane	
		fgATP/gx10^8	% of Total	fgATP/gx10^8	% of Total	fgATP/gx10^8	% of Total
Riedel-6	*Bromus tectorum*	5.08	84.0	5.65	15.0	24.9	0.4
Riedel-6	*B. tectorum*	6.75	90.0	7.63	2.5	215.0	7.4
Riedel-6	*Artemesia frigida*	4.97	79.4	6.79	13.6	12.1	6.7
Chinook-8	*Stipa comata*	7.85	85.8	7.72	2.3	62.3	11.8
Chinook-8	*Chrysopsis villosa*	4.29	84.1	11.50	6.3	80.0	9.5
Chinook-8	*Artemeisa frigida*	7.53	91.6	10.10	2.6	72.2	5.8
1928-7	*Agropyron smithii*	3.13	91.4	1.84	4.0	9.07	4.4
1948-3	*Solidago missouriensis*	2.93	57.9	1.28	2.6	55.8	39.5
1948-3	*Taraxacum officinale*	0.21	46.4	0.43	1.2	48.7	52.4
1929-10	*Solidago missouriensis*	3.34	81.5	8.48	4.5	55.9	14.0
1929-10	*Agropyron spicatum*	10.20	87.8	19.30	4.0	52.0	8.1
1972-13	*Agropyron cristatum*	15.20	87.3	10.60	7.2	74.0	5.6
1972-13	*Bromus inermis*	4.95	91.2	1.63	0.9	38.0	7.9
1972-13	*Melilotus officianalus*	12.40	91.8	1.52	0.6	62.4	0.1

the abundant coal in the 1948-3 site inhibited microorganism populations except on the surfaces of plant roots.

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APPENDIX A

Soil Characterization

Table A-1. Pedon Description of Chinook-1 soil.

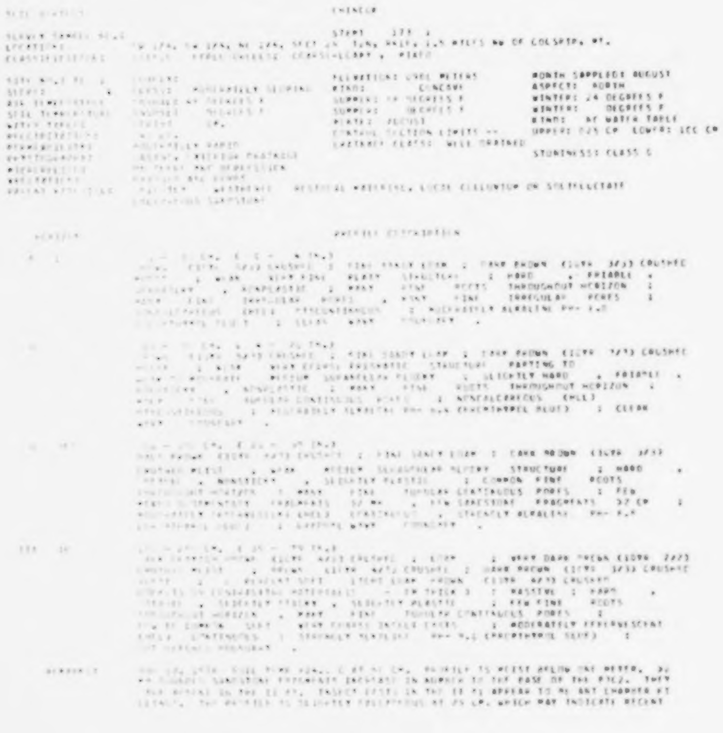

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Table A-2. Laboratory analysis of Chinook-1 soil.

```
SOIL CLASSIFICATION-ARIDIC HAPLOBOROLL                                  U. S. DEPARTMENT OF AGRICULTURE
                    COARSE-LOAMY, MIXED                                 SOIL CONSERVATION SERVICE, MTSC
SERIES - - - - - - -CHINOOK                                             NATIONAL SOIL SURVEY LABORATORY
                                                                        LINCOLN, NEBRASKA
SOIL NO - - - - - - S76MT-087-1     COUNTY - - -  ROSEBUD

GENERAL METHODS- - -1A, 1B1B, 2A1, 2B              SAMPLE NOS. 76P0534-76P0537
-------------------------------------------------------------------------------------------------------------
DEPTH   HORIZON   (- - - - - - - - - - - - - - PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B - - - - - - - - - - )RATIO
                                        FINE ( - - - - - - SAND - - - - - - )(- - -SILT- - - -) FAML  INTR  FINE  NON-  8D1
                   SAND  SILT  CLAY  CLAY  VCOS  CORS  MEDS  FNES  VFNS  COSI  FNSI  VFSI  TEXT  II    CLAY  CO3-  15-
                   2-    .05-  LT    LT    2-    1-    .5-   .25-  .10-  .05   .02   .005- SAND  .2-   TO    CLAY  BAR
                   .05   .002  .002  .0002 1     .5    .25   .10   .05   .02   .002  .002  2-.1  .02   CLAY        TO
  CM              (- - - - - - - - - - - - - - - - - PCT LT 2MM - - - - - - - - - - - - - - - - - - - -) PCT   PCT   CLAY
-------------------------------------------------------------------------------------------------------------
000-010   A1       66.8  23.1  10.1         .3    .5   3.4  43.6  19.0  14.2   8.9        47.8              10    .62
010-050   B2       67.4  20.7  11.9         .3    .8   3.9  45.8  16.6   8.7  12.0        50.8              12    .45
050-100   B3CA     68.8  18.6  12.6         .8    .7   3.5  45.5  18.3  11.7   6.9        50.5              13    .43
100-200  2A1B      55.9  26.2  17.9         .1    .6   3.5  37.2  14.5  14.0  12.2        41.4              18    .51
-------------------------------------------------------------------------------------------------------------
DEPTH  (PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2)(  BULK DENSITY  )(- - - -WATER  CONTENT- - - -) CARBONATE  (- -PH - -)
        VOL. (- - - - - - - - WEIGHT - - - - - - - -) 4A1D  4A1H  4D1    4B1C  4B1C  4B2   4C1        6E1B  3A1A  8C1A  8C1E
        GT    GT    75-20 20-5  5-2    LT    20-2  1/3-  OVEN  COLE   1/10  1/3-  15-   WRD        LT    LT    1/1   1/2
        2     75                       .074  PCT   BAR   DRY          BAR   BAR   BAR   CM/        2     .002  H2O   CACL
  CM    PCT   PCT   (- - - PCT LT 75 - - - ) LT20  G/CC  G/CC         PCT   PCT   PCT   CM         PCT   PCT
-------------------------------------------------------------------------------------------------------------
000-010  TR    0     0     TR    1           1   1.3 A                            6.3              TR          7.7   7.4
010-050  1     0     0     1     1           2   1.41  1.41  .000         10.9    5.4   .08         4    TR    8.2   7.7
050-100  2     0     0     1     2           2   1.4 A                            5.4              12    TR    8.5   8.0
100-200  TR    0     0     TR    TR          TR  1.31  1.40  .023         17.0    9.1   .11         8    TR    9.0   8.3
-------------------------------------------------------------------------------------------------------------
DEPTH (ORGANIC MATTER  ) IRON  PHOS  (- -EXTRACTABLE BASES 5B4A- -) ACTY   AL    (CAT EXCH) RATIO RATIO  CA   (BASE SAT)
       6A1A  6B1A  C/N   6C2B          6N2E  6O2D  6P2B  6Q2B        6H1A  6G1E  5A3A  5A6A  8D1   8D3   5F1   5C3   5C1
       ORGN  NITG        EXT   TOTL    CA    MG    NA    K     SUM   BACL  KCL   EXTB  NHAC  NHAC  CA    SAT   EXTB  NHAC
       CARB              FE                                    EXTB  TEA   EXT   ACTY        TO    TO    NHAC  ACTY
  CM   PCT   PCT         PCT   PCT (- - - - - - - - - - - -MEQ / 100  G- - - - - - - - - - - ) CLAY  MG    PCT   PCT   PCT
-------------------------------------------------------------------------------------------------------------
000-010  1.93  .159   12                 TR    TR    .5          .0                    9.8   .97
010-050   .85  .081   10                4.0   .0    .4                                7.9   .66
050-100   .58  .050   12                5.3   TR    .4                                4.5   .35
100-200  1.06  .039   27               24.7   .1    .4                                6.0   .34
-------------------------------------------------------------------------------------------------------------
DEPTH  (SATURATED PASTE)  NA    NA    SALT  GYP  (- - - - - - - - - - SATURATION EXTRACT 8A1- - - - - - - - - - ) ATTERBERG
        8E1   8C1B  8A    5D2   5E    8D5   6F1A  8A1A  6N1B  6O1B  6P1B  6Q1B  6I1A  6J1A  6K1C  6L1C  6M1C   4F1   4F2
        REST  PH    H2O   ESP   SAR   TOTL        EC    CA    MG    NA    K     CO3   HCO3  CL    SO4   NO3    LQID  PLST
        OHM-                          SOLU        MMHOS/                                                       LMIT  INDX
  CM    CM          PCT   PCT         PPM   PCT   CM  ( - - - - - - - - - - MEQ / LITER - - - - - - - - - - - ) PCT
-------------------------------------------------------------------------------------------------------------
000-010            7.2   42.7               410         1.24  8.6   5.5   .1    .8    .0   12.2   .3    .9    .4
010-050                                                  .208
050-100  7800      8.2   28.7                80          .40  1.6   2.0   .1    .5    .0    3.5   .1    .4    .0    26    7 C
100-200  5000      8.9   34.3          1    150          .63   .3   4.5  1.7    .5    .0    4.7   .1   1.1    .2
-------------------------------------------------------------------------------------------------------------
(A)  ESTIMATE
(B)  1:2 SOIL WATER RATIO.
(C)  BY SOIL MECHANICS LABORATORY, USDA, LINCOLN, NE.
```

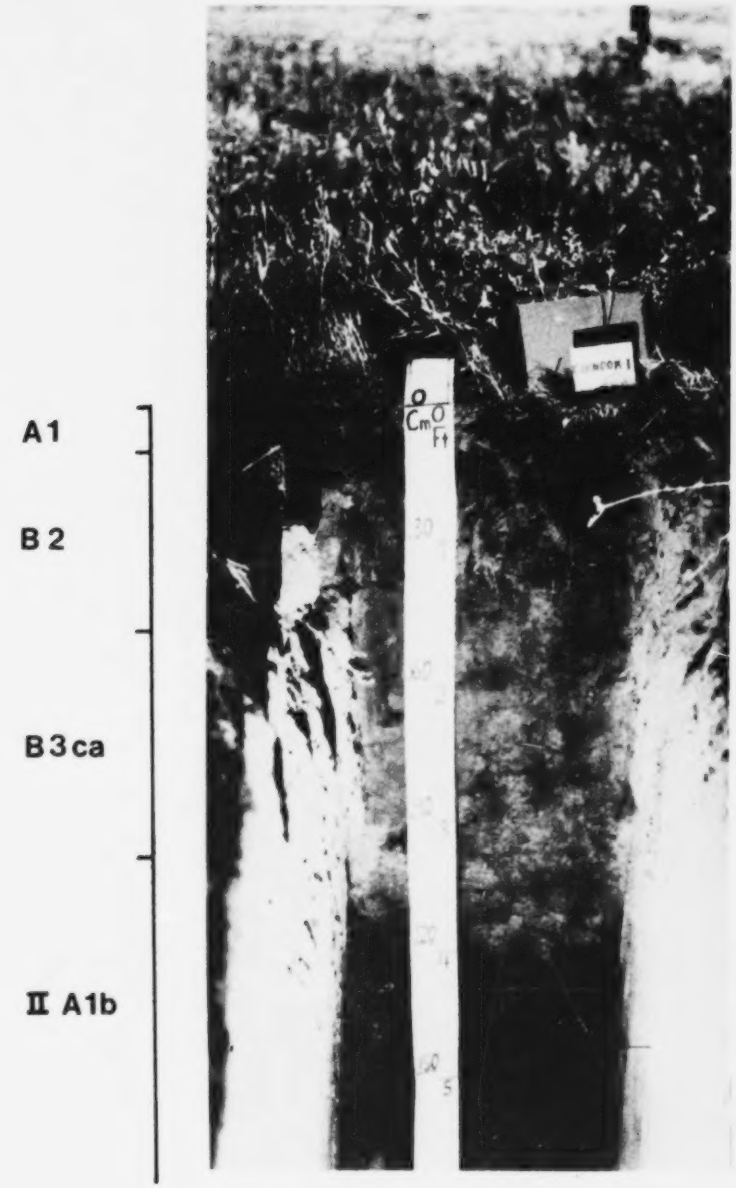
A1
B2
B3ca
II A1b
0
Cm
0
Ft
30
CHINOOK I
5

Fig. A-1. Photograph of Chinook-1 soil profile.

Table A-3. Pedon description of Boxwell-2 soil.

```
SOIL SERIES                              S76MT-087-2

SURVEY AREA NO.                          6      173  2
LOCATION            NW 1/4, SW 1/4, SE 1/4, SECT 28, T2N, R41E, 2 MILES NE OF COLSTRIP, MT.
CLASSIFICATION

SITE NUMBER         COUNTY: SEE REMARKS        ELEVATION: 1073 METERS        MONTH SAMPLED: AUGUST
SLOPE           6   CLASS:  STRONGLY SLOPING   KIND:        CONVEX           ASPECT:  SOUTHWEST
AIR TEMPERATURE     ANNUAL: 46 DEGREES F       SUMMER: 68 DEGREES F          WINTER: 24 DEGREES F
SOIL TEMPERATURE    ANNUAL:    DEGREES F       SUMMER:    DEGREES F          WINTER:    DEGREES F
WATER TABLE         DEPTH:      CM.            MONTH:  AUGUST                KIND:  NO WATER TABLE
PRECIPITATION:      [illegible] CM.            CONTROL SECTION LIMITS --     UPPER: 025 CM  LOWER: 100 CM
PERMEABILITY:       MODERATE                   DRAINAGE CLASS:  WELL DRAINED
PHYSIOGRAPHY:       ROLLING OR HILLY UPLANDS                                 STONINESS: CLASS 0
MICRORELIEF:        ON SLOPE
VEGETATION:         GRASSES AND FORBS
PARENT MATERIAL:    SLIGHTLY   WEATHERED   RESIDUAL MATERIAL, LOCAL COLLUVIUM OR SOLIFLUCTATE
                    INTERBEDDED SANDSTONE AND SHALE

    HORIZON                              PROFILE DESCRIPTION

  A 11               0 -   1 CM.  (  0 -   0 IN.)
                    DARK GRAYISH BROWN  (10YR  4/2) CRUSHED  ;  LOAM     ;  VERY DARK BROWN (10YR  2/2)
                    CRUSHED MOIST   ;  WEAK    VERY FINE   GRANULAR    STRUCTURE    ;  SOFT     ,
                    VERY FRIABLE     ,  NONSTICKY     ,  SLIGHTLY PLASTIC      ;  MANY    FINE    ROOTS
                    THROUGHOUT HORIZON   ;  MANY     FINE    TUBULAR CONTINUOUS  PORES    ;
                    NONCALCAREOUS   (HCL)   CONTINUOUS   ;  MODERATELY ALKALINE PH= 8.2
                    (BROMTHYMOL BLUE)    ;  ARBITRARY   BOUNDARY   .

  A 12               1 -   2 CM.  (  0 -   1 IN.)
                    BROWN   (10YR  4/3) CRUSHED  ;  LOAM      ;  DARK BROWN  (10YR  3/3) CRUSHED MOIST    ;
                    WEAK    VERY FINE   GRANULAR     STRUCTURE    ;  SOFT      ,  VERY FRIABLE      ,
                    NONSTICKY     ,  SLIGHTLY PLASTIC      ;  MANY     FINE     ROOTS   THROUGHOUT HORIZON   ;
                    MANY     FINE     TUBULAR CONTINUOUS  PORES    ;  NONCALCAREOUS    (HCL)    CONTINUOUS   ;
                    MODERATELY ALKALINE PH= 8.2 (BROMTHYMOL BLUE)     ;  ARBITRARY    BOUNDARY   .

  A 13               2 -   5 CM.  (  1 -   2 IN.)
                    BROWN    (10YR  4/3) CRUSHED  ;  LOAM      ;  DARK BROWN  (10YR  3/3) CRUSHED MOIST    ;
                    MODERATE     FINE     GRANULAR     STRUCTURE     ;  SLIGHTLY HARD     ,  VERY FRIABLE     ,
                    NONSTICKY     ,  SLIGHTLY PLASTIC      ;  MANY     FINE     ROOTS   THROUGHOUT HORIZON   ;
                    MANY     FINE     TUBULAR CONTINUOUS  PORES     ;  NONCALCAREOUS    (HCL)    CONTINUOUS   ;
                    MODERATELY ALKALINE PH= 8.2 (BROMTHYMOL BLUE)     ;  ARBITRARY    BOUNDARY   .

  A 14               5 -  10 CM.  (  2 -   4 IN.)
                    BROWN    (10YR  5/3) CRUSHED  ;  LOAM      ,  DARK BROWN  (10YR  3/3) CRUSHED MOIST    ;
                    MODERATE     FINE     GRANULAR     STRUCTURE     ;  SLIGHTLY HARD     ,  VERY FRIABLE     ,
                    NONSTICKY     ,  SLIGHTLY PLASTIC      ;  MANY     FINE     ROOTS   THROUGHOUT HORIZON   ;
                    MANY     FINE     TUBULAR CONTINUOUS  PORES     ;  NONCALCAREOUS    (HCL)    CONTINUOUS   ;
                    MODERATELY ALKALINE PH= 8.2 (BROMTHYMOL BLUE)     ;  ARBITRARY    BOUNDARY   .

  B 1               10 -  23 CM.  (  4 -   9 IN.)
                    YELLOWISH BROWN (10YR  5/4) CRUSHED  ;  LOAM      ;  DARK BROWN  (10YR  3/3) CRUSHED
                    MOIST    ;  MODERATE     MEDIUM  GRANULAR     STRUCTURE     ;  SLIGHTLY HARD     ,
                    FRIABLE  ,  SLIGHTLY STICKY  ,  SLIGHTLY PLASTIC      ;  MANY     FINE     ROOTS
                    THROUGHOUT HORIZON    ;  MANY     FINE     TUBULAR CONTINUOUS  PORES     ;
                    NONCALCAREOUS    (HCL)    CONTINUOUS    ;  MODERATELY ALKALINE PH= 8.2
                    (BROMTHYMOL BLUE)     ;  CLEAR    SMOOTH   BOUNDARY   .

  B 21              23 -  38 CM.  (  9 -  15 IN.)
                    BROWN    (10YR  4/3) CRUSHED  ;  SANDY CLAY LOAM  ;  V DK GRAYISH BROWN  (10YR  3/2)
                    CRUSHED MOIST    ;  WEAK     MEDIUM  PRISMATIC   DRY STRUCTURE    PARTING TO
                    MODERATE     MEDIUM  SUBANGULAR BLOCKY    ;  VERY HARD     ,  FIRM      ,
                    SLIGHTLY STICKY  ,  SLIGHTLY PLASTIC      ;  COMMON TO MANY  FINE    ROOTS
                    BETWEEN PEDS      ;  MANY     FINE     TUBULAR CONTINUOUS  PORES     ;  NONCALCAREOUS
                    (HCL)    CONTINUOUS    ;  MODERATELY ALKALINE PH= 8.2  ;  CLEAR    WAVY     BOUNDARY   .

  B 22              38 -  50 CM.  ( 15 -  20 IN.)
                    YELLOWISH BROWN (10YR  5/4) CRUSHED  ;  SANDY CLAY LOAM  ;  BROWN    (10YR  4/3)
                    CRUSHED MOIST    ;  WEAK     MEDIUM  PRISMATIC   STRUCTURE    PARTING TO  MODERATE
                    MEDIUM  SUBANGULAR BLOCKY    ;  VERY HARD     ,  FIRM      ,  SLIGHTLY STICKY  ,
                    SLIGHTLY PLASTIC      ;  COMMON TO MANY  FINE    ROOTS   BETWEEN PEDS      ;  MANY
                    FINE     TUBULAR CONTINUOUS  PORES     ;  MANY     SOFT     VERY COARSE INSECT CASTS     ;
                    NONCALCAREOUS    (HCL)    CONTINUOUS    ;  MODERATELY ALKALINE PH= 8.2
                    (BROMTHYMOL BLUE)     ;  CLEAR    SMOOTH   BOUNDARY   .

  B 3               50 -  60 CM.  ( 20 -  24 IN.)
                    PALE BROWN  (10YR  6/3) CRUSHED  ;  LOAM      ;  BROWN    (10YR  4/3) CRUSHED MOIST    ;
                    VERY WEAK    COARSE  PRISMATIC   STRUCTURE    PARTING TO  WEAK     MEDIUM
                    SUBANGULAR BLOCKY    ;  VERY HARD     ,  FIRM      ,  SLIGHTLY STICKY  ,
                    SLIGHTLY PLASTIC      ;  COMMON TO MANY  FINE    ROOTS   BETWEEN PEDS      ;  MANY
                    FINE     TUBULAR CONTINUOUS  PORES     ;  MANY     SOFT     VERY COARSE INSECT CASTS     ;
                    MODERATELY EFFERVESCENT (HCL)   CONTINUOUS    ;  MODERATELY ALKALINE PH= 8.2
                    (BROMTHYMOL BLUE)     ;  CLEAR    SMOOTH   BOUNDARY   .

  C 1CA             60 -  75 CM.  ( 24 -  30 IN.)
                    VERY PALE BROWN (10YR  7/3) CRUSHED  ;  VERY FINE SANDY LOAM     ;  BROWN    (10YR  5/3)
                    CRUSHED MOIST    ;  WEAK     MEDIUM  SUBANGULAR BLOCKY    STRUCTURE     ;  HARD      ,
                    FRIABLE  ,  SLIGHTLY STICKY  ,  SLIGHTLY PLASTIC      ;  FEW FINE     ROOTS
                    BETWEEN PEDS      ;  MANY     FINE     TUBULAR CONTINUOUS  PORES     ;  MANY
                    PROMINENT    CALCIUM CARBONATE CUTANS     IN ROOT CHANNELS AND/OR PORES     ;
                    COMMON TO MANY  SOFT     THREAD-LIKE MASSES OF LIME    ,  MANY     SOFT     VERY COARSE
                    INSECT CASTS      ;  VIOLENTLY EFFERVESCENT  (HCL)    DISCONTINUOUS     ;
                    STRONGLY ALKALINE    PH= 8.8 (BROMTHYMOL BLUE)     ;  CLEAR    SMOOTH   BOUNDARY   .

  C 2CA             75 - 100 CM.  ( 30 -  39 IN.)
                    VERY PALE BROWN (10YR  7/3) CRUSHED  ;  VERY FINE SANDY LOAM     ;  BROWN    (10YR  5/3)
                    CRUSHED MOIST    ;  MASSIVE  ;  HARD      ,  FRIABLE  ,  SLIGHTLY STICKY  ,
                    SLIGHTLY PLASTIC      ;  FEW FINE     ROOTS   BETWEEN PEDS      ;  MANY     FINE
                    TUBULAR CONTINUOUS  PORES     ;  MANY     PROMINENT    CALCIUM CARBONATE CUTANS
                    IN ROOT CHANNELS AND/OR PORES     ;  COMMON TO MANY  SOFT     THREAD-LIKE
                    MASSES OF LIME    ,  MANY     SOFT     VERY COARSE INSECT CASTS     ;
                    VIOLENTLY EFFERVESCENT  (HCL)    CONTINUOUS    ;  STRONGLY ALKALINE    PH= 8.8
                    (BROMTHYMOL BLUE)     ;  GRADUAL SMOOTH   BOUNDARY   .

  C 3              100 - 145 CM.  ( 39 -  57 IN.)
                    PALE BROWN  (10YR  6/3) CRUSHED  ;  VERY FINE SANDY LOAM     ;  BROWN    (10YR  5/3)
                    CRUSHED MOIST    ;  MASSIVE  ;  SLIGHTLY HARD     ,  VERY FRIABLE      ,
                    SLIGHTLY STICKY  ,  SLIGHTLY PLASTIC      ;  FEW FINE     ROOTS   BETWEEN PEDS      ;
                    MANY     FINE     TUBULAR CONTINUOUS  PORES     ;  VIOLENTLY EFFERVESCENT (HCL)
                    CONTINUOUS    ;  STRONGLY ALKALINE    PH= 8.8 (BROMTHYMOL BLUE)     ;  NOT REACHED
                    BOUNDARY   .

  REMARKS           JULY 11, 1976  SOIL TEMP [illegible] C AT 50 CM.  PH OF LOWEST HORIZON WAS 8.8 WITH TH
                    YMOL BLUE WAS 7.9 WITH DIGITAL PH METER.
```

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Table A-4. Laboratory analyses of Boxwell-2.

SOIL CLASSIFICATION-BOROLLIC CAMBORTHID
FINE-LOAMY, MIXED
SERIES - - - - - - - -YAMAC

SOIL NO - - - - - - - S76MT-087-2   COUNTY - - - ROSEBUD

GENERAL METHODS- - -1A, 1B1B, 2A1, 2B   SAMPLE NOS. 76P0530-76P0549

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, MTSC
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA

DEPTH	HORIZON	(- - PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B - -																)RATIO
					FINE	(- - SAND				- -)(	- -SILT-		- -)					
		SAND 2-.05	SILT .05-.002	CLAY LT .002	CLAY LT .0002	VCOS 2-1	CORS 1-.5	MEDS .5-.25	FNES .25-.10	VFNS .10-.05	COSI .05-.02	FNSI .02-.002	VFSI .005-.002	FAML TEXT SAND 2-.1	INTR II .2-.02	FINE CLAY TO CLAY	NON-CO3-CLAY	8D1 15-BAR TO
CM		(- - PCT LT 2MM													- -)	PCT	PCT	CLAY
000-001	A11	48.7	36.4	14.9		.2	2.5	2.5	22.4	21.1	24.3	12.1		27.6			15	.86
001-002	A12	48.9	39.1	12.1		.4	.5	1.6	23.1	23.3	25.5	13.6		25.6			12	.68
002-005	A13	49.0	37.9	13.1		.2	.4	1.3	22.2	24.9	25.4	12.5		24.1			13	.44
005-010	A14	49.1	37.6	13.3		.1	.4	1.4	23.3	23.9	24.4	13.2		25.2			13	.43
010-022	A15	46.9	33.8	19.3		.1	.2	1.1	22.3	23.2	23.5	10.3		23.7			19	.38
022-038	B21	48.7	31.0	20.3		TR	.2	1.1	23.8	23.6	21.1	9.9		25.1			20	.41
038-050	B22	49.3	30.9	19.8		.1	.1	.9	22.5	25.7	20.9	10.0		23.6			20	.40
050-060	B23	47.1	33.2	19.7		.1	.1	.8	19.4	26.7	22.9	10.3		20.4			20	.41
060-075	B3CA	38.1	35.3	26.6		TR	.1	.6	12.8	24.6	24.3	11.0		13.5			20	.35
075-100	C1CA	42.3	34.9	22.8		TR	.1	.3	11.5	30.4	22.0	12.9		11.9			17	.36
100-145	C2	46.3	34.7	19.0		.0	.1	.3	13.3	32.6	21.9	12.8		13.7			19	.38
000-005	(A)																	

DEPTH	(PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2)							(BULK DENSITY		)	(- - -WATER CONTENT-			- - -)	CARBONATE		(- -PH	- -)
	VOL.	(- - WEIGHT					- -)	4A1D	4A1H	4D1	4B1C	4B1C	4B2	4C1	6E1B	3A1A	8C1A	8C1E
	GT 2	GT 75	75-20	20-5	5-2	LT .074	20-2 PCT	1/3-BAR	OVEN DRY	COLE	1/10 BAR	1/3-BAR	15-BAR	WRD CM/	LT 2	LT .002	1/1 H2O	1/2 CACL
CM	PCT	PCT	(- - - PCT LT 75			- - -)	LT20	G/CC	G/CC		PCT	PCT	PCT	CM	PCT	PCT		
000-001	TR	0	0	TR	TR		TR	1.1 B					12.8				7.0	6.3
001-002	TR	0	0	TR	TR		TR	1.1 B					8.1				6.5	5.9
002-005	TR	0	0	TR	TR		TR	1.1 B					5.8				6.3	5.6
005-010	TR	0	0	TR	TR		TR	1.2 B					5.7				6.2	5.6
010-022	TR	0	0	0	TR		TR	1.43	1.48	.003		14.7	7.4	.10			6.4	5.9
022-038	TR	0	0	TR	TR		TR	1.59	1.67	.012		16.8	8.4	.13			6.6	6.1
038-050	0	0	0	0	0		0						7.9		TR		6.9	6.3
050-060	0	0	0	0	0		0						8.1		3		8.0	7.5
060-075	0	0	0	0	0		0	1.62	1.77	.028		14.2	9.3	.08	18	7	8.4	7.9
075-100	0	0	0	0	0		0						8.2		21	6	8.6	8.1
100-145	0	0	0	0	0		0	1.48	1.61	.028		19.4	7.2	.18	15		8.7	8.1
000-005								1.10	1.23	.040		21.3						

DEPTH	(ORGANIC MATTER		)	IRON	PHOS	(- -EXTRACTABLE BASES 5B4A-			- -)		ACTY	AL	(CAT EXCH)		RATIO	RATIO	CA	(BASE	SAT)
	6A1A	6B1A	C/N	6C2B		6N2E	6O2D	6P2B	6Q2B		6H1A	6G1E	5A3A	5A6A	8D1	8D3	5F1	5C3	5C1
	ORGN CARB	NITG		EXT FE	TOTL	CA	MG	NA	K	SUM EXTB	BACL TEA	KCL EXT	EXTB ACTY	NHAC	NHAC TO	CA TO	SAT NHAC	EXTB ACTY	NHAC
CM	PCT	PCT		PCT	PCT	(- - - -				-MEQ / 100	G- - -			- - -)	CLAY	MG	PCT	PCT	PCT
000-001	3.47	.376	9			13.7	4.4	TR	1.4	19.5	5.0		24.5	18.2	1.22	3.1	75	80	107
001-002	2.32	.207	11			8.2	2.9	.0	1.0	12.1	4.3		16.4	13.5	1.12	2.8	61	74	90
002-005	1.30	.118	11			5.8	2.2	.0	.7	8.7	3.4		12.1	10.5	.80	2.6	55	72	83
005-010	1.14	.106	11			6.7	2.1	.0	.7	9.5	3.2		12.7	11.0	.83	3.2	61	75	86
010-022	.88	.089	10			8.2	3.2	.0	.8	12.2	2.9		15.1	14.0	.73	2.6	59	81	87
022-038	.66	.071	9			8.1	4.4	.0	.5	13.0	2.6		15.6	15.4	.76	1.8	53	83	84
038-050	.56	.063	9			8.1	5.3	.0	.0	13.4	1.9		15.3	14.7	.74	1.5	55	88	91
050-060	.58	.070	8				8.5	.0	.4					13.9	.71				
060-075	.40	.046	9				8.9	.0	.4					11.0	.41				
075-100	.25	.029	9				13.8	.0	.3					10.1	.44				
100-145	.22	.022	10				17.1	.1	.3					10.6	.56				
000-005																			

DEPTH	(SATURATED	PASTE)		NA	NA	SALT	GYP	(- - -			SATURATION	EXTRACT 8A1-					- - -)	ATTERBERG	
	8E1	8C1B	8A	5D2	5E	8D5	6F1A	8A1A	6N1B	6O1B	6P1B	6Q1B	6I1A	6J1A	6K1C	6L1C	6M1C	4F1	4F2
	REST OHM-CM	PH	H2O	ESP	SAR	TOTL SOLU		EC MMHOS/CM	CA	MG	NA	K	CO3	HCO3	CL	SO4	NO3	LQID LMIT	PLST INDX
CM			PCT	PCT		PPM	PCT		(- - -			MEQ / LITER					- - -)	PCT	
000-001		6.4	75.0			1000		1.71	11.5	7.3	.1	2.3	.0	16.8	.5	.8	.0		
001-002								.10C											
002-005								.10C											
005-010								.10C											
010-022								.10C											
022-038								.10C										28	9 D
038-050								.10C											
050-060								.20C											
060-075								.20C											
075-100	3900	8.4						.20C											
100-145	3700	8.3	39.2	1	1	100		.36	.6	2.1	1.0	.1	.0	2.5	.1	.5	.1	28	9 D
000-005																			

(A) CLOD OF A11, A12, AND A13 FOR BULK DENSITY AND MOISTURE RETENTION.
(B) ESTIMATE.
(C) 1:2 SOIL WATER RATIO.
(D) BY SOIL MECHANICS LABORATORY, USDA, LINCOLN, NE.

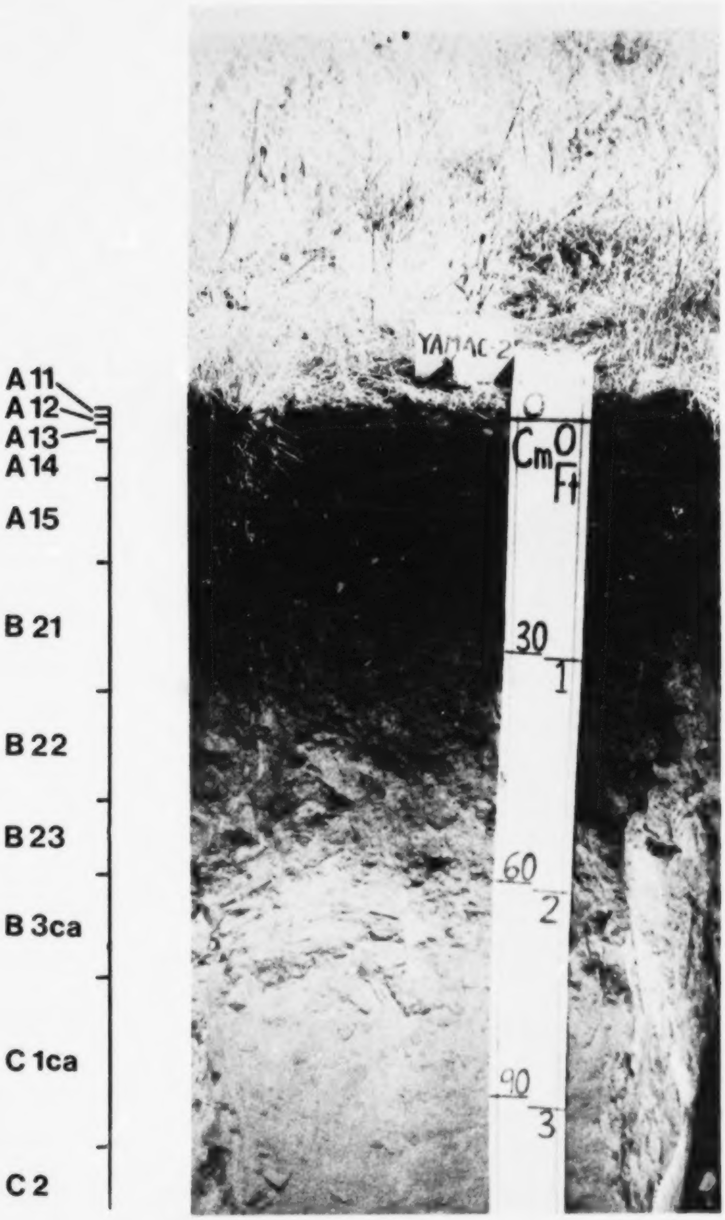
A 11
A 12
A 13
A 14
A 15
B 21
B 22
B 23
B 3ca
C 1ca
C 2
YAMAC-2
0
Cm
0
Ft
30
1
60
2
90
3

Fig. A-2. Photograph of Boxwell-2 profile.

Table A-5. Pedon description of 1948-3 soil.

```
SOIL SERIES:                         1948 SERIES

SERVICE SAMPLE NO.:                  [illegible]
LOCATION:            [illegible] 1/4, [illegible] 1/4, [illegible] 1/4, SECT [illegible], T[illegible], R[illegible], [illegible] MI EAST OF COLSTRIP, MT
CLASSIFICATION:

SITE NO.:  [illegible]     [illegible]          ELEVATION: [illegible] METERS      MONTH SAMPLED: AUGUST
SLOPE:     [illegible]     CLASS: NEARLY LEVEL  KIND:     PLANE                    ASPECT:
AIR TEMPERATURE:    [illegible] DEGREES F      SUMMER: [illegible] DEGREES F       WINTER: 24 DEGREES F
SOIL TEMPERATURE:   [illegible]  DEGREES F     SUMMER:   DEGREES F                 WINTER:   DEGREES F
WATER TABLE:        DEPTH:    CM.              MONTH:  AUGUST                      KIND:  NO WATER TABLE
PRECIPITATION:      [illegible] CM.            CONTROL SECTION LIMITS --           UPPER: 025 CM  LOWER: 100 CM
PERMEABILITY:       MODERATELY RAPID           DRAINAGE CLASS:  WELL DRAINED
PHYSIOGRAPHY:       [illegible] INTERIOR DRAINAGE                                  STONINESS: CLASS 0
VEGETATION:         GRASSES AND FORBS AND SHRUBS
PARENT MATERIAL:    [illegible]    WEATHERED   UNCONSOLIDATED MINERAL SEDIMENTS
                    [illegible] SANDSTONE    AND MIXED LITHOLOGY

   HORIZON                                PROFILE DESCRIPTION

   [illegible]         [illegible] CM. [illegible] IN.)
               [illegible] (10YR 4/2) CRUSHED , LOAM    ; VERY DARK GRAY (10YR 3/1)
               [illegible]   ; WEAK    FINE    PLATY   STRUCTURE    ; SOFT    ,
               [illegible]   , NONSTICKY    , NONPLASTIC   ; MANY    FINE    ROOTS
               [illegible]   ; MANY    MEDIUM  IRREGULAR   PORES    , FEW FINE
               [illegible] CONTINUOUS  PORES    ; MODERATELY EFFERVESCENT (HCL)   CONTINUOUS  ;
               MODERATELY ALKALINE [illegible] PH)   ; ARBITRARY   BOUNDARY   .

   [illegible]         [illegible] CM. [illegible] IN.)
               [illegible] (10YR 5/2) CRUSHED  ; LOAM     ; V DK GRAYISH BROWN (10YR 3/2)
               [illegible]   ; WEAK    FINE    PLATY   STRUCTURE   ; SOFT    ,
               [illegible]   , NONSTICKY    , NONPLASTIC   ; MANY    FINE    ROOTS
               [illegible]   ; MANY    MEDIUM  IRREGULAR   PORES    , FEW FINE
               [illegible] CONTINUOUS  PORES    ; MODERATELY EFFERVESCENT (HCL)   CONTINUOUS  ;
               MODERATELY ALKALINE [illegible] PH)   ; ABRUPT  SMOOTH  BOUNDARY   .

   [illegible]         [illegible] CM. [illegible] IN.)
               [illegible] (10YR 5/2) CRUSHED  ; LOAM     ; DARK GRAYISH BROWN (10YR 4/2)
               CRUSHED MOIST    ; VERY PALE BROWN (10YR 7/4) CRUSHED  ; LT. YELLOWISH BROWN
               (10YR 6/4) CRUSHED MOIST    , [illegible]   COARSE  PLATY   STRUCTURE   ;
               SLIGHTLY HARD   , VERY FRIABLE     , NONSTICKY    , SLIGHTLY PLASTIC    ;
               [illegible]   ROOTS   BETWEEN PEDS    ; MANY    MEDIUM  IRREGULAR   PORES    ,
               [illegible]   [illegible] CONTINUOUS PORES   ; FEW SANDSTONE   FRAGMENTS   >2 CM   ;
               MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ; MODERATELY ALKALINE PH- 8.4
               [illegible]   ; ABRUPT  WAVY    BOUNDARY   .

   [illegible]         [illegible] CM. [illegible] IN.)
               [illegible] (10YR 5/2) CRUSHED  ; LOAM     ; DARK GRAYISH BROWN (10YR 4/2)
               CRUSHED MOIST    ; VERY PALE BROWN (10YR 7/4) CRUSHED  ; LT. YELLOWISH BROWN
               (10YR 6/4) CRUSHED MOIST    ; [illegible] PERCENT HARD    SILT LOAM   VERY DARK GRAY
               [illegible]   - CM THICK )   ;
               [illegible]   STRUCTURE   ; SOFT    , VERY FRIABLE    ,
               NONSTICKY    , SLIGHTLY PLASTIC    ; MANY    FINE    ROOTS   THROUGHOUT HORIZON   ;
               MANY    [illegible]   IRREGULAR   PORES    ; VIOLENTLY EFFERVESCENT (HCL)   CONTINUOUS  ;
               MODERATELY ALKALINE [illegible] PH)   ; ARBITRARY   BOUNDARY   .

   [illegible]         [illegible] CM. [illegible] IN.)
               [illegible] (10YR 5/2) CRUSHED  ; LOAM     ; DARK GRAYISH BROWN (10YR 4/2)
               CRUSHED MOIST    ; VERY PALE BROWN (10YR 7/4) CRUSHED  ; LT. YELLOWISH BROWN
               (10YR 6/4) CRUSHED MOIST    , COMMON  MEDIUM & COARSE    PROMINENT
               [illegible] (10YR 6/6) CRUSHED MOTTLES  ; [illegible] PERCENT HARD    SILT LOAM
               VERY DARK GRAY (10YR 3/1) CRUSHED [illegible] BANDS [illegible]  - CM THICK )   ; MASSIVE  ;
               SLIGHTLY HARD   , VERY FRIABLE     , NONSTICKY    , SLIGHTLY PLASTIC    ; FEW
               [illegible]   ROOTS   THROUGHOUT HORIZON   ; MANY    FINE    IRREGULAR   PORES    ;
               [illegible] EFFERVESCENT (HCL)   CONTINUOUS   ; MODERATELY ALKALINE PH- 8.4
               [illegible]   ; ARBITRARY   BOUNDARY   .

   [illegible]         [illegible] CM. [illegible] IN.)
               [illegible] (10YR 5/2) CRUSHED  ; LOAM     ; BLACK    (10YR 2/1) CRUSHED
               MOIST    ; LT. YELLOWISH BROWN (10YR 6/4) [illegible]    ; YELLOWISH BROWN (10YR 5/4)
               [illegible]   MOIST    ; COMMON  MEDIUM & COARSE    PROMINENT   BROWNISH YELLOW
               (10YR 6/6) CRUSHED MOTTLES  ; [illegible] PERCENT HARD    SILT LOAM   VERY DARK GRAY
               (10YR 3/1) CRUSHED CHARCOAL [illegible]   - CM THICK )   ; MASSIVE  ;
               SLIGHTLY HARD   , VERY FRIABLE     , NONSTICKY    , SLIGHTLY PLASTIC    ; FEW
               [illegible]   ROOTS   THROUGHOUT HORIZON   ; COMMON FINE    IRREGULAR   PORES    ; [illegible]
               [illegible]   FRAGMENTS   >2 CM    ; VIOLENTLY EFFERVESCENT (HCL)   CONTINUOUS  ;
               MODERATELY ALKALINE PH- 8.4 [illegible]   ; ARBITRARY   BOUNDARY   .

   [illegible]         [illegible] CM. [illegible] IN.)
               LT. YELLOWISH BROWN (10YR 6/4) CRUSHED  ; LOAM     ; LIGHT OLIVE BROWN  (2.5Y 5/4)
               CRUSHED MOIST    ; [illegible] BROWN  (10YR 5/3) CRUSHED  ; DARK GRAYISH BROWN
               (2.5Y 4/2) CRUSHED MOIST    ; COMMON  MEDIUM & COARSE    PROMINENT
               BROWNISH YELLOW (10YR 6/6) CRUSHED MOTTLES  ; [illegible] PERCENT HARD    SILT LOAM
               VERY DARK GRAY (10YR 3/1) CRUSHED CHARCOAL BANDS [illegible]  - CM THICK )   ; MASSIVE  ;
               SLIGHTLY HARD   , VERY FRIABLE     , SLIGHTLY STICKY  , SLIGHTLY PLASTIC    ;
               [illegible]   ROOTS   THROUGHOUT HORIZON   ; FEW FINE    IRREGULAR   PORES    ; FEW
               [illegible]   FRAGMENTS   >2 CM    , MODERATELY EFFERVESCENT (HCL)   CONTINUOUS  ;
               MODERATELY ALKALINE [illegible] PH)   ; NOT REACHED BOUNDARY   .

   REMARKS:    [illegible] 1/4, [illegible] 1/4, [illegible] 1/4, SECT [illegible], T[illegible], R[illegible]
               [illegible] SERIES AT [illegible], [illegible] IN 1948 [illegible] COUNTY NEAR COLSTRIP
               [illegible]   FRAGMENTS ARE COMMON THR
               [illegible]   LARGE FRAGMENT OF SHALE OCCU
               [illegible]   MATERIALS ASSOCIATED WITH COAL FRAGMENTS HAS COL
               [illegible]   IN [illegible] COAL POCKETS AT 110 CM.  THE
               [illegible]   SHALE AND SILTSTONE WITH SILT TO
```

Reproduced from best available copy.

Table A-6. Laboratory analyses of 1948-3 soil.

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, MTSC
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA

SOIL CLASSIFICATION-

SERIES - - - - - - - -MINE SPOIL

SOIL NO - - - - - - - S76MT-087-3   COUNTY - - - ROSEBUD

GENERAL METHODS- - -1A, 1B1B, 2A1, 2B   SAMPLE NOS. 76P0550-76P0557

DEPTH	HORIZON	(- - - PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B															- - -)	RATIO
						(- - - SAND				- - -)	(- - -SILT	- - -)						
		SAND 2-.05	SILT .05-.002	CLAY LT .002	FINE CLAY LT .0002	VCOS 2-1	COS 1-.5	MEDS .5-.25	FNES .25-.10	VFNS .10-.05	COSI .05-.02	FNSI .02-.002	VFSI .005-.002	FAML TEXT SAND 2-.1	INTR II .2-.02	FINE CLAY TO CLAY	NON-CO3-CLAY	8D1 15-BAR TO CLAY
CM		(- - -							PCT LT 2MM						- - -)	PCT	PCT	
000-001	A11	48.6	37.6	13.8		1.4	1.4	2.2	26.3	17.3	19.8	17.8		31.3				.87
001-002	A12	51.1	35.2	13.7		1.3	1.9	2.7	28.1	17.1	16.3	18.9		34.0				.64
002-005	A13	45.4	36.4	18.2		.6	1.1	2.1	27.3	14.3	17.9	18.5		31.1				.47
005-010	C1	49.9	34.5	15.6		1.2	.9	1.8	31.0	15.0	18.4	16.1		34.9				.55
010-050	C2	45.9	36.8	17.3		.5	1.0	1.9	28.6	13.9	18.5	18.3		32.0				.73
050-100	C3	55.0	31.7	13.3		.6	.8	2.2	34.8	16.6	17.0	14.7		38.4				1.00
100-153	C4	32.7	48.1	19.2		.9	.3	1.0	13.7	16.8	24.9	23.2		15.9				.69
-------	COAL																	

DEPTH	(PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2)							(BULK DENSITY		)	(- - - -WATER CONTENT			- - -)	CARBONATE		(- -PH - -)	
	VOL.	(- - - WEIGHT					- - -)	4A1D	4A1H	4D1	4B1C	4B1C	4B2	4C1	6E1B	3A1A	8C1A	8C1E
	GT 2	GT 75	75-20	20-5	5-2	LT .074	20-2 PCT	1/3-BAR	OVEN DRY	COLE	1/10 BAR	1/3-BAR	15-BAR	WRD CM/	LT 2	LT .002	1/1 H2O	1/2 CACL
CM	PCT	PCT	(- - -	PCT LT 75		- - -)	LT20	G/CC	G/CC		PCT	PCT	PCT	CM	PCT	PCT		
000-001	3	0	0	2	3		5	1.2 A					12.0		7		7.6	7.3
001-002	5	0	TR	4	5		9	1.3 A					8.8		8		7.7	7.4
002-005	8	0	2	7	3		10	1.55	1.62	.014		18.1	8.6	.14	9		7.9	7.2
005-010	10	0	0	7	9		16	1.70	1.74	.007		15.8	8.6	.11	12		8.0	7.4
010-050	9	0	0	7	9		16	1.40	1.44	.009		20.4	12.6	.10	11		7.6	7.3
050-100	12	0	0	11	12		23	1.3 A					13.3		10		7.5	7.3
100-153	6	0	0	8	6		14	1.19	1.25	.016		24.0	13.3	.12	9		7.6	7.2
--------									1.21								6.0	5.8

DEPTH	(ORGANIC MATTER		)	IRON	PHOS	(- -EXTRACTABLE BASES 5B6A-			-)		ACTY	AL	(CAT EXCH)		RATIO	RATIO	CA	(BASE	SAT)
	6A1A	6B1A	C/N	6C2B		6N2E	6O2D	6P2B	6Q2B		6H1A	6G1E	5A3A	5A6A	8D1	8D3	5F1	5C3	5C1
	ORGN CARB	NITG		EXT FE	TOTL	CA	MG	NA	K	SUM EXTB	BACL TEA	KCL EXT	EXTB ACTY	NHAC	NHAC TO	CA TO	SAT NHAC	EXTR ACTY	NHAC
CM	PCT	PCT		PCT	PCT	(- - -			-MEQ / 100	G- - -				- - -)	CLAY	MG	PCT	PCT	PCT
000-001	5.11	.333	15				8.2	TR	1.2					24.9	1.80				
001-002	5.01	.213	24				8.4	TR	.8					22.8	1.66				
002-005	4.16	.145	29				9.5	TR	.6					21.9	1.20				
005-010	2.83	.092	31				10.9	.3	.6					17.7	1.13				
010-050	5.94	.129	46				16.2	1.1	.2					30.5	1.76				
050-100	5.52	.131	42				21.2	.6	.2					34.0	2.57				
100-153	5.28	.131	40				19.4	.1	.2					39.5	1.77				
-------	13.08	.959	14	.0C							15.2D	.0E							

DEPTH	(SATURATED PASTE)			NA	NA	SALT	GYP	(- - -				SATURATION EXTRACT 8A1-				- - -)	ATTERBERG	
	8E1	8C1B	8A	5D2	5E	8D5	6F1A	8A1A	6N1B	6O1B	6P1B	6Q1B	6I1A	6J1A	6K1C	6L1C	6M1C	4F1	4F2
	REST OHM-CM	PH	H2O	ESP	SAR	TOTL SOLU		EC MMHOS/CM	CA	MG	NA	K	CO3	HCO3	CL	SO4	NO3	LQID LMIT	PLST INDX
CM	CM		PCT	PCT		PPM	PCT		(- - -				MEQ / LITER				- - -)	PCT	
000-001		6.8	63.2			2000	0	3.83	29.1	15.1	.6	4.6	.0	3.8	3.9	3.2	.0		
001-002		7.5	43.2			620		1.80	14.0	6.3	.2	1.9	.0	14.1	2.5	1.4	.0		
002-005		7.5	41.0			420		1.31	9.3	4.9	.7	1.1	.0	10.6	1.4	1.5	.0		
005-010		7.6	40.0	1	2	430		1.47	6.7	4.8	4.2	1.0	.0	5.1	4.2	5.8	.0		
010-050		7.2	40.9	2	4	1100		3.48	14.6	12.4	13.5	.3	.0	3.5	19.1	21.2	.0		
050-100	830	7.1	41.3	1	2	1900	0	4.96	29.9	31.3	8.7	.2	.0	2.5	28.6	38.1	.0		
100-153	2200	7.3	43.7			510		1.51	7.9	8.8	1.4	.1	.0	3.5	3.9	9.6	.0		
-------		5.9	122.0		1	1000		1.11	4.4	6.6	2.0	.2	.0	5.3	1.0	3.9	TR		

(A) ESTIMATE
(B) ORGANIC CARBON FOR COAL SAMPLE ON <0.25 MM MATERIAL = 35.4 PERCENT AND ON THE <0.002 MM MATERIAL = 37.0 PERCENT.
(C) FE FOR THE <0.25 MM MATERIAL = 0 PERCENT.
(D) ACIDITY FOR THE <0.25 MM MATERIAL = 31.7 MEQ PER 100 G.
(E) AL FOR THE <0.25 MM MATERIAL = 0 PERCENT.

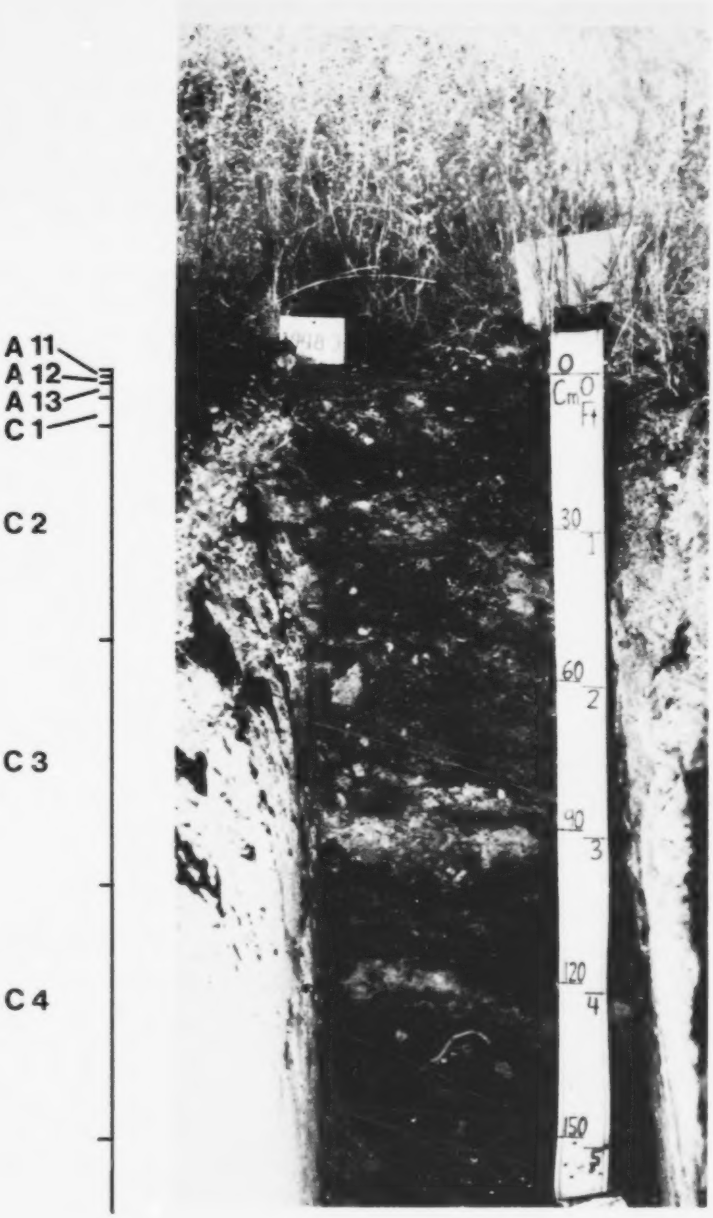
A 11
A 12
A 13
C 1
C 2
C 3
C 4
0
Cm
0
Ft
30
1
60
2
90
3
120
4
150
5

Fig. A-3. Photograph of 1948-3 soil profile.

Table A-7. Pedon description of Ethridge-4 soil.

```
SOIL SERIES:                              ETHRIDGE

SURVEY SAMPLE NO.:                        S76MT   173   4
LOCATION:            SW 1/4, NE 1/4, SE 1/4, SECT 2 T1N, R41E, 7 MI SE OF COLSTRIP, MT.
CLASSIFICATION:      ARIDIC   ARGIBOROLLS:   FINE , MONTMORILLONITIC

SITE NO.? [illegible]  [illegible]                  ELEVATION: 1060 METERS       MONTH SAMPLED: AUGUST
SLOPE:          4    CLASS:   NEARLY LEVEL          KIND:        CONVEX          ASPECT:  NORTHEAST
AIR TEMPERATURE:     ANNUAL: 45 DEGREES F           SUMMER: 68 DEGREES F         WINTER: 24 DEGREES F
SOIL TEMPERATURE:    ANNUAL:    DEGREES F           SUMMER:    DEGREES F         WINTER:    DEGREES F
WATER TABLE:         DEPTH:      CM.                MONTH:  AUGUST               KIND:  NO WATER TABLE
PRECIPITATION:       40 CM.                         CONTROL SECTION LIMITS --    UPPER: 010 CM  LOWER: 050 CM
PERMEABILITY:        MODERATELY SLOW                DRAINAGE CLASS:  WELL DRAINED
PHYSIOGRAPHY:        [illegible] UPLAND DRAINAGE                                 STONINESS: CLASS 0
MICRORELIEF:         ON SLOPE AND DEPRESSION
VEGETATION:          GRASSES AND FORBS AND SHRUBS
PARENT MATERIAL:     SLIGHTLY    WEATHERED    RESIDUAL MATERIAL, LOCAL COLLUVIUM OR SOLIFLUCTATE
                     CALCAREOUS SHALE    ,     HORIZONTAL

  HORIZON                                 PROFILE DESCRIPTION

  A 11               0 -   3 CM.  ( 0 -   1 IN.)
                     PALE BROWN  (10YR  6/3) CRUSHED  ;  LOAM      ;  BROWN   (10YR  4/3) CRUSHED MOIST    ;
                     WEAK TO MODERATE    FINE    PLATY    STRUCTURE    ;  SLIGHTLY HARD    ,
                     VERY FRIABLE     ,  SLIGHTLY STICKY  ,  SLIGHTLY PLASTIC     ;  MANY    FINE
                     ROOTS   THROUGHOUT HORIZON    ;  MANY     FINE    VESICULAR   PORES    ;
                     NONCALCAREOUS   (HCL)   CONTINUOUS    ;  MODERATELY ALKALINE PH- 8.2
                     (BROMTHYMOL BLUE)    ;  ABRUPT    [illegible]   .

  A 12               3 -   7 CM.  ( 1 -   3 IN.)
                     PALE BROWN  (10YR  6/3) CRUSHED  ;  SILT LOAM     ;  BROWN   (10YR  4/3) CRUSHED
                     MOIST    ;  WEAK TO MODERATE    FINE    PLATY    STRUCTURE    ;  HARD      ,  FRIABLE  ,
                     SLIGHTLY STICKY  ,  SLIGHTLY PLASTIC     ;  MANY     FINE     ROOTS
                     THROUGHOUT HORIZON   ;  MANY     FINE    VESICULAR   PORES    ;  NONCALCAREOUS
                     (HCL)   CONTINUOUS    ;  MODERATELY ALKALINE PH- 8.2 (BROMTHYMOL BLUE)    ;
                     [illegible]    BOUNDARY    .

  [illegible]        [illegible] -  [illegible] CM.  ( 3 -  [illegible] IN.)
                     PALE BROWN  (10YR  6/3) CRUSHED   ;  SILTY CLAY LOAM  ;  BROWN    (10YR  4/3) CRUSHED
                     MOIST    ;  WEAK TO MODERATE    FINE    PLATY    STRUCTURE    ;  HARD      ,  FRIABLE  ,
                     STICKY   ,  PLASTIC  ;  MANY     FINE    ROOTS   THROUGHOUT HORIZON    ;  COMMON
                     FINE    TUBULAR PORES    ;  NONCALCAREOUS   (HCL)   CONTINUOUS    ;
                     MODERATELY ALKALINE PH- 8.2 (BROMTHYMOL BLUE)    ;  ARBITRARY    BOUNDARY    .

  [illegible]        [illegible] -  15 CM.  ( [illegible] -   6 IN.)
                     PALE BROWN  (10YR  6/3) CRUSHED   ;  SILTY CLAY LOAM  ;  BROWN    (10YR  4/3) CRUSHED
                     MOIST    ;  WEAK      FINE    PLATY    STRUCTURE    ;  VERY HARD    ,  FIRM     ,
                     STICKY   ,  PLASTIC  ;  MANY     FINE    ROOTS   THROUGHOUT HORIZON    ;  COMMON
                     FINE    TUBULAR CONTINUOUS  PORES    ;  NONCALCAREOUS   (HCL)   CONTINUOUS    ;
                     MODERATELY ALKALINE PH- 8.2 (BROMTHYMOL BLUE)    ;  ABRUPT  WAVY    BOUNDARY    .

  B 21T              15 -  19 CM.  ( 6 -   7 IN.)
                     BROWN    (10YR  5/3) CRUSHED   ;  SILTY CLAY    ;  BROWN    (10YR  4/3) CRUSHED MOIST    ;
                     MODERATE    FINE    PRISMATIC    STRUCTURE    PARTING TO  STRONG  FINE &  MEDIUM
                     SUBANGULAR BLOCKY    ;  HARD       ,  FIRM      ,  STICKY    ,  VERY PLASTIC     ;
                     MANY     FINE     ROOTS   THROUGHOUT HORIZON    ;  MANY     FINE     TUBULAR CONTINUOUS
                     PORES    ;  [illegible]  FAINT   CLAY SKINS  ON PED FACES     ;  NONCALCAREOUS
                     (HCL)   CONTINUOUS    ;  MODERATELY ALKALINE PH- 8.2 (BROMTHYMOL BLUE)    ;  CLEAR
                     SMOOTH   BOUNDARY    .

  B 22T              19 -  31 CM.  ( 7 -  12 IN.)
                     BROWN    (10YR  5/3) CRUSHED   ;  SILTY CLAY    ;  BROWN    (10YR  4/3) CRUSHED MOIST    ;
                     MODERATE    FINE    PRISMATIC    STRUCTURE    PARTING TO  STRONG  FINE &  MEDIUM
                     SUBANGULAR BLOCKY    ;  HARD       ,  FIRM      ,  STICKY    ,  VERY PLASTIC     ;
                     COMMON  FINE    ROOTS   BETWEEN PEDS      ;  MANY     FINE     TUBULAR CONTINUOUS
                     PORES    ;  COMMON  FAINT   CLAY SKINS  ON PED FACES     ;  NONCALCAREOUS   (HCL)
                     CONTINUOUS    ,  MODERATELY ALKALINE PH- 8.2   ;  CLEAR   WAVY     BOUNDARY    .

  B 3T               31 -  [illegible] CM.  ( 12 -  22 IN.)
                     LT. YELLOWISH BROWN (10YR  6/4) CRUSHED  ;  SILTY CLAY LOAM  ;  YELLOWISH BROWN
                     (10YR  5/4) CRUSHED MOIST    ;  WEAK     VERY COARSE PRISMATIC   STRUCTURE
                     PARTING TO  MODERATE    MEDIUM  SUBANGULAR BLOCKY    ;  HARD      ,  FIRM      ,
                     STICKY   ,  PLASTIC  ;  COMMON  FINE    ROOTS   BETWEEN PEDS      ;  MANY     FINE
                     TUBULAR CONTINUOUS   PORES    ;  COMMON  FAINT   CLAY SKINS
                     [illegible]    ;  MODERATELY EFFERVESCENT (HCL)   CONTINUOUS    ;
                     STRONGLY ALKALINE   PH- [illegible] (BROMTHYMOL BLUE)    ;  GRADUAL SMOOTH  BOUNDARY    .

  C 1                [illegible] -  [illegible] CM.  ( 22 -  39 IN.)
                     VERY PALE BROWN (10YR  7/3) CRUSHED  ;  SILTY CLAY LOAM  ;  YELLOWISH BROWN (10YR  5/4)
                     CRUSHED MOIST    ;  WEAK     VERY COARSE PRISMATIC   STRUCTURE    PARTING TO  WEAK
                     COARSE  SUBANGULAR BLOCKY    ;  HARD      ,  FRIABLE  ,  SLIGHTLY STICKY  ,  PLASTIC  ;
                     FEW FINE     ROOTS   BETWEEN PEDS      ,  COMMON TO MANY  FINE     TUBULAR CONTINUOUS
                     PORES    ;  FEW FAINT   CLAY SKINS  IN ROOT CHANNELS AND/OR PORES    ;
                     MODERATELY EFFERVESCENT (HCL)   CONTINUOUS    ;  STRONGLY ALKALINE   PH- 9.0
                     (BROMTHYMOL BLUE)    ;  GRADUAL WAVY     BOUNDARY    .

  C 2                [illegible] -  [illegible] CM.  ( 39 -  [illegible] IN.)
                     PALE YELLOW (2.5Y  7/4) CRUSHED   ;  LOAM      ;  LIGHT OLIVE BROWN   (2.5Y  5/4)
                     CRUSHED MOIST    ;  MASSIVE  ;  SLIGHTLY HARD    ,  VERY FRIABLE     ,
                     SLIGHTLY STICKY  ,  SLIGHTLY PLASTIC     ;  FEW FINE     ROOTS   BETWEEN PEDS     ;
                     COMMON TO MANY  FINE     TUBULAR CONTINUOUS   PORES    ;  MODERATELY EFFERVESCENT
                     (HCL)   CONTINUOUS    ;  STRONGLY ALKALINE   PH- 9.0 (BROMTHYMOL BLUE)    ;
                     NOT REACHED BOUNDARY    .

  REMARKS:           AUG 11, 1976 SOIL TEMP [illegible] C AT 50 CM.  GYPSUM CRYSTALS LINE SOME 1MM VOIDS IN
                     THE C1 HORIZON.
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Table A-8. Laboratory analyses of Ethridge-4 soil.

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SOIL CLASSIFICATION-ARIDIC ARGIBOROLL                                                       U. S. DEPARTMENT OF AGRICULTURE
                    FINE, MONTMORILLONITIC                                                  SOIL CONSERVATION SERVICE, MTSC
SERIES - - - - - - -ETHRIDGE                                                                NATIONAL SOIL SURVEY LABORATORY
                                                                                            LINCOLN, NEBRASKA
SOIL NO - - - - - - S76MT-087-4      COUNTY - - -  ROSEBUD

GENERAL METHODS- - -1A, 1B1B, 2A1, 2B              SAMPLE NOS. 76P0558-76P0567

--------------------------------------------------------------------------------------------------------------------------------
DEPTH    HORIZON    (- - - - - - - - - - - - - - - - - PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B - - - - - - - - - - )RATIO
                                           FINE ( - - - - - - SAND - - - - - - )(- - -SILT- - - -) FAML  INTR  FINE  NON-    8D1
                        SAND   SILT   CLAY   CLAY  VCOS  CORS  MEDS  FNES  VFNS  COSI  FNSI  VFSI  TEXT  II    CLAY  CO3-    15-
                        2-     .05-   LT     LT    2-    1-    .5-   .25-  .10-  .05   .02   .005- SAND  .2-   TO    CLAY    BAR
                        .05    .002   .002   .0002 1     .5    .25   .10   .05   .02   .002  .002  2-.1  .02   CLAY          TO
 CM                  (- - - - - - - - - - - - - - - - - - - - PCT LT 2MM - - - - - - - - - - - - - - - - - - -)  PCT   PCT    CLAY
--------------------------------------------------------------------------------------------------------------------------------
000-001   A11           28.9   48.2   22.9           .5    .3   1.0  12.2  14.9  23.8  24.4        14.0                      .40
001-002   A12           27.6   46.1   26.3           .1    .3    .9  12.0  14.3  22.5  23.6        13.3                      .45
002-005   A13           24.9   41.7   33.5           .3    .4    .8  10.8  12.5  20.5  21.2        12.3                      .25
005-010   A14           22.1   39.6   38.3           .1    .2    .5   9.1  12.2  19.3  20.3         9.9                      .25
010-019   B21T          18.3   42.7   39.0           .1    .1    .3   6.5  11.3  20.4  22.3         7.0                      .26
019-031   B22T          20.7   46.7   32.6           .1    .2    .6   7.6  12.2  21.9  24.8         8.5                      .38
031-050   B23           21.2   47.4   31.4           .1    .3    .6   8.1  12.1  20.1  27.3         9.1                      .33
050-100   B3            28.5   47.0   24.5           .1    .1    .7  11.8  15.8  20.3  26.7        12.7                      .38
100-152   C1            57.9   27.8   14.3           .4    .4   1.6  32.2  23.3  14.5  13.3        34.6                      .38
000-005     (A)

--------------------------------------------------------------------------------------------------------------------------------
DEPTH  (PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2)(  BULK DENSITY   )(- - - -WATER   CONTENT- - - -) CARBONATE   (- -PH - -)
        VOL. (- - - - - - - WEIGHT - - - - - - -) 4A1D  4A1H  4D1    4B1C  4B1C  4B2   4C1          6E1B  3A1A  8C1A   8C1E
        GT    GT     75-20 20-5  5-2    LT   20-2 1/3-  OVEN  COLE    1/10  1/3-  15-   WPD          LT    LT    1/1    1/2
        2     75                       .074  PCT  BAR   DRY           BAR   BAR   BAR   CM/          2     .002  H2O    CACL
 CM     PCT   PCT   (- - - PCT LT 75 - - - ) LT20 G/CC  G/CC          PCT   PCT   PCT   CM           PCT   PCT
--------------------------------------------------------------------------------------------------------------------------------
000-001  TR      0     0    TR    TR          TR  1.4 B                             9.1                TR         6.9   6.7
001-002  TR      0     0    TR    TR          TR  1.4 B                            11.8                TR         7.0   6.4
002-005  TR      0     0    TR    TR          TR  1.5 B                             8.3                TR         6.8   6.4
005-010  TR      0     0    TR    TR          TR  1.55  1.68  .028          18.8    9.6  .15           TR         6.9   6.3
010-019  TR      0     0    TR    TR          TR  1.49  1.67  .040          20.5   10.3  .16           TR         6.8   6.2
019-031   0      0     0     0     0           0                                   12.3                TR         7.6   7.1
031-050   0      0     0     0     0           0                                   10.3                16         8.3   7.8
050-100   0      0     0     0     0           0  1.54  1.61  .015          18.4    9.2  .14           15         9.8   8.2
100-152  TR      0     0    TR    TR          TR  1.45  1.50  .012          15.0    5.4  .14           13         8.9   8.2
000-005                                           1.41  1.52  .025          21.0

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DEPTH (ORGANIC MATTER   ) IRON  PHOS  (- -EXTRACTABLE BASES 5B4A- -)  ACTY  AL    (CAT EXCH) RATIO RATIO    CA   (BASE  SAT)
        6A1A  6B1A   C/N   6C2B        6N2E  6O2D  6P2B  6Q2B         6H1A  6G1E  5A3A  5A6A   8D1   8D3    5F1  5C3    5C1
        ORGN  NITG         EXT   TOTL    CA    MG    NA    K    SUM   BACL  KCL   EXTB  NHAC   NHAC  CA     SAT  EXTB   NHAC
        CARB               FE                                   EXTB  TEA   EXT   ACTY          TO  TO     NHAC ACTY
 CM     PCT   PCT          PCT   PCT (- - - - - - - - - - -MEQ / 100  G- - - - - - - - - - -)  CLAY  MG  . PCT  PCT    PCT
--------------------------------------------------------------------------------------------------------------------------------
000-001  2.99   .235   13                9.8   5.1    TR   1.6  16.5   2.4         18.9  14.3   .62   1.9    69    87   115
001-002  1.62   .140   12                8.5   4.7    .0   1.1  14.3   2.3         16.6  14.1   .57   1.8    60    86   101
002-005  1.38   .121   11                8.9   5.0    .0   1.1  15.0   3.3         18.3  14.8   .44   1.8    60    82   101
005-010  1.01   .098   10                9.3   5.0    .0   1.1  15.4   2.3         17.7  16.2   .42   1.9    57    87    95
010-019   .75   .077   10               10.1   6.0    .0    .7  16.8   2.5         19.3  17.9   .46   1.7    56    87    94
019-031   .79   .085    9                      8.7    TR    .6                           19.3   .59
031-050   .62   .064   10                      9.2    TR    .4                           11.7   .37
050-100   .29   .027   11                     22.9    .3    .4                           10.1   .41
100-152   .14   .018    8                     10.9   1.0    .2                            6.2   .43
000-005

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DEPTH  (SATURATED PASTE)   NA     NA   SALT  GYP  (- - - - - - - - - - SATURATION EXTRACT 8A1- - - - - - - - - - ) ATTERBERG
        8F1  8C1B   8A    5D2     5E   8D5   6F1A  8A1A  6N1B  6O1B  6P1B  6Q1B   6I1A  6J1A  6K1C  6L1C  6M1C    4F1  4F2
        REST  PH    H2O   ESP     SAR TOTL           EC    CA    MG     NA    K    CO3   HCO3    CL   SO4   NO3    LQID PLST
        OHM-                          SOLU       MMHOS/                                                           LMIT INDX
 CM     CM          PCT   PCT         PPM   PCT    CM  ( - - - - - - - - - - MEQ / LITER - - - - - - - - - - - - ) PCT
--------------------------------------------------------------------------------------------------------------------------------
000-001         6.6  49.6               890        2.23  12.9  11.9    .2   2.9     .0  21.7   1.1   1.4    .0
001-002                                             .20C
002-005                                             .10C
005-010                                             .10C
010-019                                             .10C                                                          32  15 D
019-031                                             .20C
031-050                                             .20C
050-100  3400   8.4  37.3    2    2     130         .48    .4   2.8   2.1    .1     .0   3.7    .1    .5    .2
100-152  1500   8.5  31.8    8    7     560        2.45   1.1  10.2  16.0    .2     .0   1.9    .9  24.5    .0    22   4 D
000-005

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(A)  CLOD OF A11, A12, AND A13 FOR BULK DENSITY AND MOISTUR RETENTION.
(B)  ESTIMATE
(C)  1:2 SOIL WATER RATIO.
(D)  BY SOIL MECHANICS LABORATORY, USDA, LINCOLN, NE.
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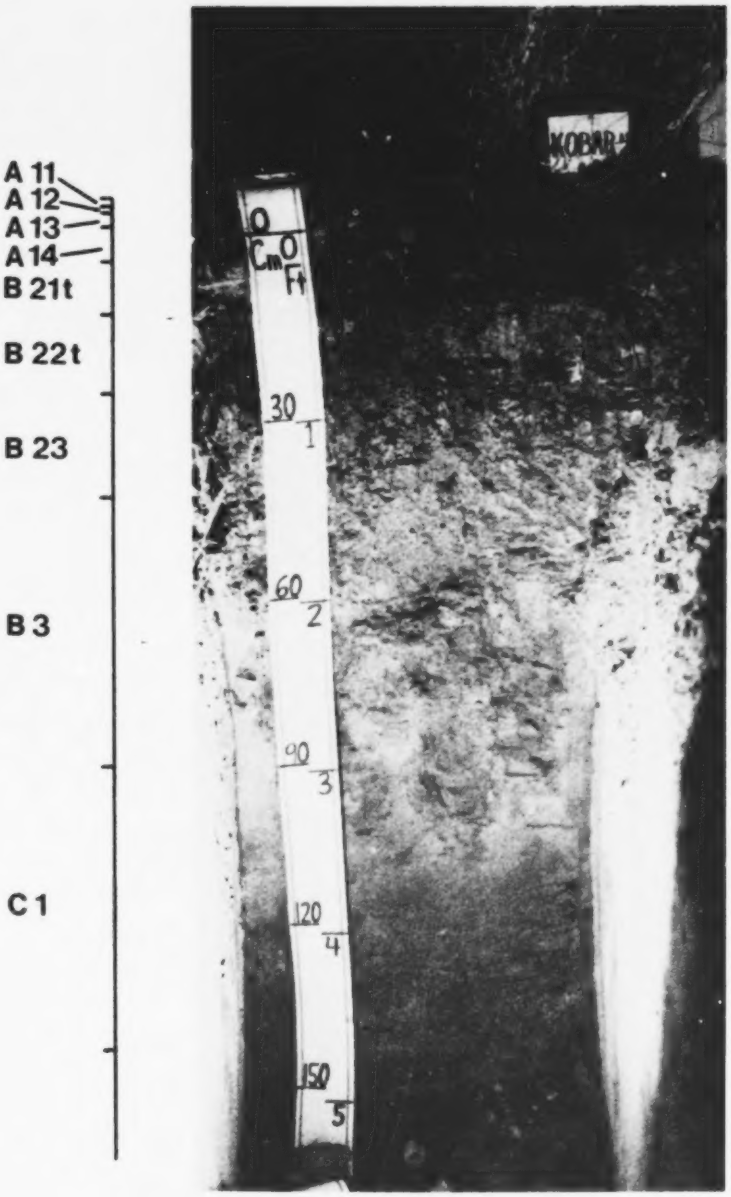
A 11
A 12
A 13
A 14
B 21t
B 22t
B 23
B 3
C 1
0
Cm
0
Ft
30
1
60
2
90
3
120
4
150
5
KOBAR

Fig. A-4. Photograph of Ethridge-4 soil profile.

Table A-9. Pedon description of 1928-5 soil.

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SOIL SERIES:                          1928 SPOILS

SURVEY SAMPLE NO.:                    0     173  5
LOCATION:          NE 1/4, SE 1/4, NE 1/4, SECT 3 T1N, R41E, 1 MI SE OF COLSTRIP, MT.
CLASSIFICATION:

SITE NO.:   5     COUNTY: SEE REMARKS       ELEVATION: 1010 METERS        MONTH SAMPLED: AUGUST
SLOPE:      1     CLASS:  NEARLY LEVEL      KIND:      PLANE              ASPECT:
AIR TEMPERATURE:  ANNUAL: 46 DEGREES F      SUMMER: 68 DEGREES F          WINTER: 24 DEGREES F
SOIL TEMPERATURE: ANNUAL:    DEGREES F      SUMMER:    DEGREES F          WINTER:    DEGREES F
WATER TABLE:      DEPTH:      CM.           MONTH: AUGUST                 KIND:  NO WATER TABLE
PRECIPITATION:    36. CM.                   CONTROL SECTION LIMITS --     UPPER: 025 CM  LOWER: 100 CM
PERMEABILITY:     RAPID                     DRAINAGE CLASS:  SOMEWHAT EXCESSIVELY DRAINED
PHYSIOGRAPHY:     ROLLING OR HILLY UPLANDS                                STONINESS: CLASS 0
VEGETATION:       GRASSES AND FORBS AND SHRUBS
PARENT MATERIAL:  SLIGHTLY    WEATHERED   UNCONSOLIDATED MINERAL SEDIMENTS
                  CALCAREOUS SANDSTONE    AND CALCAREOUS SILTSTONE

  HORIZON                               PROFILE DESCRIPTION

 A 11             0 -   1 CM.  ( 0 -   0 IN.)
                  BROWN   (10YR  5/3) CRUSHED  ;  LOAMY FINE SAND  ;  BROWN   (10YR  4/3) CRUSHED
                  MOIST    ;  WEAK     FINE     PLATY   STRUCTURE   PARTING TO  WEAK     FINE
                  GRANULAR     ;  SOFT     ,  VERY FRIABLE      ,  NONSTICKY     ,  NONPLASTIC   ;
                  MANY    FINE    ROOTS   THROUGHOUT HORIZON   ;  MANY     FINE     IRREGULAR   PORES    ;
                  MILDLY EFFERVESCENT (HCL)  CONTINUOUS   ;  MODERATELY ALKALINE PH- 8.0
                  (BROMTHYMOL BLUE)   ;  ARBITRARY   BOUNDARY   .

 A 12             1 -   2 CM.  ( 0 -   1 IN.)
                  BROWN   (10YR  5/3) CRUSHED  ;  LOAMY FINE SAND  ;  BROWN   (10YR  4/3) CRUSHED
                  MOIST    ;  WEAK     FINE     PLATY   STRUCTURE   PARTING TO  WEAK     FINE
                  GRANULAR     ;  SOFT     ,  VERY FRIABLE      ,  NONSTICKY     ,  NONPLASTIC   ;
                  MANY    FINE    ROOTS   THROUGHOUT HORIZON   ;  MANY     FINE     IRREGULAR   PORES    ;
                  MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ;  MODERATELY ALKALINE PH- 8.2
                  (BROMTHYMOL BLUE)   ;  ARBITRARY   BOUNDARY   .

 A 13             2 -   5 CM.  ( 1 -   2 IN.)
                  BROWN   (10YR  5/3) CRUSHED  ;  LOAMY FINE SAND  ;  BROWN   (10YR  4/3) CRUSHED
                  MOIST    ;  WEAK     FINE     PLATY   STRUCTURE   PARTING TO  WEAK     FINE
                  GRANULAR     ;  SOFT     ,  VERY FRIABLE      ,  NONSTICKY     ,  NONPLASTIC   ;
                  MANY    FINE    ROOTS   THROUGHOUT HORIZON   ;  MANY     FINE     IRREGULAR   PORES    ;
                  MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ;  MODERATELY ALKALINE PH- 8.4  ;
                  ABRUPT  SMOOTH  BOUNDARY   .

 C 14             5 -  10 CM.  ( 2 -   4 IN.)
                  LIGHT BROWNISH GRAY (2.5Y  6/2) CRUSHED  ;  FINE SANDY LOAM  ;  LIGHT OLIVE BROWN
                  (2.5Y  5/4) CRUSHED MOIST    ;  MODERATE     MEDIUM  PLATY    STRUCTURE    ;  SOFT     ,
                  VERY FRIABLE      ,  NONSTICKY     ,  NONPLASTIC    ;  MANY     FINE     ROOTS
                  THROUGHOUT HORIZON    ;  MANY     FINE     IRREGULAR    PORES     ;
                  MODERATELY EFFERVESCENT (HCL)   CONTINUOUS    ;  STRONGLY ALKALINE    PH- 8.8
                  (BROMTHYMOL BLUE)    ;  ABRUPT  WAVY     BOUNDARY    .

 C  1            10 -  20 CM.  (  4 -   8 IN.)
                  LIGHT GRAY  (2.5Y  7/2) CRUSHED  ;  FINE SANDY LOAM  ;  GRAYISH BROWN   (2.5Y  5/2)
                  CRUSHED MOIST     ;  FEW FINE     PROMINENT    STRONG BROWN     (7.5YR 5/8) CRUSHED
                  MOTTLES  ;  30  PERCENT SLIGHTLY HARD   FINE SANDY LOAM PALE BROWN  (10YR  6/3)
                  CRUSHED BANDS  20    -  CM THICK )   ;  MODERATE     MEDIUM  PLATY    STRUCTURE     ;
                  SLIGHTLY HARD     ,  VERY FRIABLE      ,  NONSTICKY     ,  NONPLASTIC    ;  MANY
                  FINE    ROOTS   BETWEEN PEDS      ,  COMMON  FINE     IRREGULAR    PORES     ;
                  VIOLENTLY EFFERVESCENT  (HCL)   CONTINUOUS   ;  STRONGLY ALKALINE    PH- 8.8
                  (BROMTHYMOL BLUE)    ;  CLEAR    WAVY     BOUNDARY    .

 C  2            20 -  50 CM.  (  8 -  20 IN.)
                  LIGHT GRAY  (2.5Y  7/2) CRUSHED  ;  FINE SANDY LOAM  ;  GRAYISH BROWN   (2.5Y  5/2)
                  CRUSHED MOIST     ;  40  PERCENT VERY HARD    FINE SANDY LOAM BROWN    (10YR  5/3)
                  CRUSHED BANDS  20    -  CM THICK )   ;  MASSIVE  ;  SLIGHTLY HARD      ,
                  VERY FRIABLE      ,  NONSTICKY     ,  NONPLASTIC    ;  COMMON  FINE     ROOTS
                  THROUGHOUT HORIZON    ;  MANY     FINE     IRREGULAR    PORES     ;  FEW SANDSTONE
                  FRAGMENTS    >2 CM    ;  VIOLENTLY EFFERVESCENT  (HCL)   CONTINUOUS    ;
                  STRONGLY ALKALINE    PH- 8.8 (BROMTHYMOL BLUE)    ;  ARBITRARY    BOUNDARY    .

 C  3            50 - 100 CM.  ( 20 -  39 IN.)
                  LIGHT GRAY  (2.5Y  7/2) CRUSHED  ;  FINE SANDY LOAM  ;  GRAYISH BROWN   (2.5Y  5/2)
                  CRUSHED MOIST    ;  BROWN    (10YR  4/3) CRUSHED  ;  DARK BROWN  (10YR  3/3) CRUSHED
                  MOIST    ;  10  PERCENT VERY HARD    FINE SANDY LOAM BROWN    (10YR  5/3) EXTERIOR
                  POCKETS OF CONTRASTING MATERIAL    -  CM THICK )   ;  MASSIVE  ;  SLIGHTLY HARD     ,
                  VERY FRIABLE      ,  NONSTICKY     ,  NONPLASTIC    ;  COMMON  FINE     ROOTS
                  THROUGHOUT HORIZON    ;  MANY     FINE     IRREGULAR    PORES     ;
                  VIOLENTLY EFFERVESCENT  (HCL)   CONTINUOUS    ;  STRONGLY ALKALINE    PH- 8.8  ;
                  ARBITRARY    BOUNDARY    .
 C  4           100 - 200 CM.  ( 39 -  79 IN.)
                  LIGHT GRAY  (2.5Y  7/2) CRUSHED  ;  FINE SANDY LOAM  ;  GRAYISH BROWN   (2.5Y  5/2)
                  CRUSHED MOIST     ;  30  PERCENT SLIGHTLY HARD   FINE SANDY LOAM PALE BROWN  (10YR  6/3)
                  CRUSHED BANDS  20    -  CM THICK )   ;  MASSIVE  ;  SOFT     ,  FRIABLE  ,
                  NONSTICKY     ,  NONPLASTIC    ;  COMMON  FINE     ROOTS   THROUGHOUT HORIZON    ;
                  MANY     FINE     IRREGULAR    PORES     ;  VIOLENTLY EFFERVESCENT  (HCL)   CONTINUOUS    ;
                  STRONGLY ALKALINE    PH- 8.8 (BROMTHYMOL BLUE)    ;  NOT REACHED BOUNDARY    .

  REMARKS:        STRIP-MINE SPOILS NEAR COLSTRIP, MONTANA RELEVELED IN 1928. AUG. 10, 1976.  SOIL
                   TEMP =22.5 C AT 50 CM.  INTERMITTENT BANDS OF A1 MATERIAL OCCUR IN CRATER UPWAR
                  D SHAPES AT 30-60 CM IN DEPTH.  THESE DEPOSITIONAL STRUCTURES ARE 40 CM WIDE, 15
                   CM HIGH AND ARE ORIENTED NORMAL TO THE DIRECTION THE SPOIL PLATFORM WAS BUILT.
                   THE BANDS OFTEN SEPARATE MATERIAL OF DIFFERING LITHOLOGY.  THYMOL BLUE INDICATO
                  R GIVES PH VALUES0.5 TO 1.0 UNITS HIGHER THAN METER.  PLANT ROOTS IN C1 GROW HOR
                  IZONTALLY IN STRUCTURAL VOIDS UNTIL REACHING A VERTICAL VOID LARGE ENOUGH FOR DO
                  WNWARD GROWTH.
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Table A-10. Laboratory analyses of 1928-5 soil.

```
SOIL CLASSIFICATION-                                                                    U. S. DEPARTMENT OF AGRICULTURE
                                                                                        SOIL CONSERVATION SERVICE, MTSC
SERIES - - - - - - -SPOIL MATERIAL                                                      NATIONAL SOIL SURVEY LABORATORY
                                                                                        LINCOLN, NEBRASKA
SOIL NO - - - - - - - S76MT-087-5    COUNTY - - -  ROSEBUD

GENERAL METHODS- - -1A, 1B1B, 2A1, 2B             SAMPLE NOS. 76P0568-76P0577

------------------------------------------------------------------------------------------------------------------------
 DEPTH   HORIZON   (- - - - - - - - - - - - - - PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B - - - - - - - - - - )RATIO
                                      FINE ( - - - - - SAND - - - - - - )(- - -SILT- - - -) FAML  INTR  FINE  NON-   8D1
                    SAND  SILT  CLAY  CLAY  VCOS  CORS  MEDS  FNES  VFNS  COSI  FNSI  VFSI  TEXT    II  CLAY  CO3-   15-
                      2-  .05-    LT    LT    2-    1-   .5-  .25-  .10-   .05   .02 .005-  SAND   .2-    TO  CLAY   BAR
                     .05  .002  .002 .0002     1    .5   .25   .10   .05   .02  .002  .002  2-.1   .02  CLAY          TO
  CM              (- - - - - - - - - - - - - - - - - - - PCT LT 2MM - - - - - - - - - - - - - - - - - - -) PCT   PCT  CLAY
------------------------------------------------------------------------------------------------------------------------
000-001  A11        76.4  15.1   8.5          .1   2.3   6.7  54.0  13.3   8.6   6.5        63.1                    1.02
001-002  A12        79.8  12.6   7.6          TR   1.5   5.3  58.7  14.3   6.1   6.5        65.5                     .75
002-005  A13        80.1  11.9   8.0          .1    .7   4.5  60.0  14.8   5.3   6.6        65.3                     .50
005-010  AC         78.8  13.9   7.3          .5   1.0   8.0  59.5   9.8   5.0   8.9        69.0                     .48
010-020  C1         81.3  12.1   6.6          .1    .6   7.7  62.3  10.6   4.6   7.5        70.7                     .47
020-050  C2         78.7  12.5   8.8          .4    .4   7.2  60.2  10.5   5.0   7.5        68.2                     .41
050-100  C3         73.7  14.3  12.0          .4    .5   4.9  52.3  15.6   6.5   7.8        58.1                     .41
100-200  C4         73.0  15.7  11.3          .5    .5   5.1  52.8  14.1   7.0   8.7        58.9                     .43
100-200  C4  (A)    78.4  17.9   3.7        39.8  14.7   6.5   9.1   8.3   7.6  10.3        70.1                     .57
000-005      (B)

------------------------------------------------------------------------------------------------------------------------
DEPTH  (PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2)(  BULK DENSITY  )(- - - -WATER  CONTENT- - - -) CARBONATE  (- -PH - -)
        VOL. (- - - - - - - WEIGHT - - - - - - -) 4A1D  4A1H  4D1   4B1C  4B1C  4B2   4C1         6E1B  3A1A  8C1A  8C1E
        GT    GT    75-20 20-5  5-2    LT   20-2  1/3-  OVEN  COLE  1/10  1/3-  15-   WRD           LT    LT   1/1   1/2
        2     75                     .074   PCT   BAR   DRY         BAR   BAR   BAR   CM/         2     .002   H2O   CACL
 CM     PCT   PCT   (- - - PCT LT 75 - - - ) LT20 G/CC  G/CC        PCT   PCT   PCT   CM          PCT   PCT
------------------------------------------------------------------------------------------------------------------------
000-001   TR     0     0    TR    TR          TR 1.3 C                           8.7                 6           7.4   7.2
001-002   TR     0     0    TR    TR           1 1.3 C                           5.7                 7           7.6   7.1
002-005    1     0     0     2    TR           2 1.3 C                           4.0                 7           7.9   7.3
005-010    1     0     0     1     1           2  1.46  1.55  .020        13.3   3.5   .14           7           7.9   7.3
010-020    2     0     0     2     2           4  1.60  1.60  .000         9.2   3.1   .10           7           8.2   7.5
020-050    1     0     0     1     1           2 1.5 C                           3.6                 9           6.4   7.7
050-100    3     2     2     2     1           3  1.39  1.42  .007        14.0   4.9   .12          11           8.5   7.8
100-200    6     3     4     2     1           3 1.4 C                           4.9                11           8.5   7.8
100-200                                                                                             58           8.8   7.9
000-005                                           1.28  1.34  .015        13.3

------------------------------------------------------------------------------------------------------------------------
DEPTH (ORGANIC MATTER  ) IRON  PHOS  (- -EXTRACTABLE BASES 5B4A- -) ACTY   AL   (CAT EXCH) RATIO RATIO   CA   (BASE SAT)
        6A1A  6B1A   C/N  6C2B        6N2E  6O2D  6P2B  6Q2B        6H1A  6G1E  5A3A  5A6A   8D1   8D3   5F1   5C3   5C1
        ORGN  NITG        EXT   TOTL    CA    MG    NA     K   SUM  BACL   KCL  EXTB  NHAC  NHAC    CA   SAT  EXTB  NHAC
        CARB              FE                                  EXTB   TEA   EXT  ACTY          TO    TO  NHAC  ACTY
  CM    PCT   PCT         PCT   PCT (- - - - - - - - - - -MEQ / 100  G- - - - - - - - - - ) CLAY    MG   PCT   PCT   PCT
------------------------------------------------------------------------------------------------------------------------
000-001 4.21  .304    14                     4.1    TR   1.2                          14.6  1.72
001-002 2.56  .152    17                     2.8    TR    .5                           8.3  1.09
002-005 1.06  .071    15                     2.4    .0    .3                           6.0   .75
005-010  .59  .044    13                     2.9    .0    .3                           4.4   .60
010-020  .38  .032    12                     3.3    .0    .3                           3.7   .56
020-050  .35  .028    13                     3.7    .0    .3                           4.0   .45
050-100  .45  .036    13                     4.4    .0    .5                           4.5   .38
100-200  .49  .039    13                     4.8    .0    .3                           4.7   .42
100-200
000-005

------------------------------------------------------------------------------------------------------------------------
DEPTH  (SATURATED PASTE)   NA    NA  SALT   GYP (- - - - - - - - - SATURATION EXTRACT 8A1- - - - - - - - - ) ATTERBERG
        8E1  8C1B    8A   5D2    5E   8D5  6F1A  8A1A  6N1B  6O1B  6P1B  6Q1B  6I1A  6J1A  6K1C  6L1C  6M1C   4F1   4F2
       REST    PH   H2O   ESP   SAR  TOTL          EC    CA    MG    NA     K   CO3  HCO3    CL   SO4   NO3  LQID  PLST
       OHM-                         SOLU       MMHOS/                                                     LMIT  INDX
  CM    CM          PCT   PCT         PPM   PCT    CM  ( - - - - - - - - - MEQ / LITER - - - - - - - - - - - ) PCT
------------------------------------------------------------------------------------------------------------------------
000-001        6.7  65.7               920        1.77  12.6   5.2    .1   3.9    .0  15.6   1.6    .7    .0
001-002        7.2  45.0               360        1.10   8.2   2.6    .1   1.5    .0   9.9    .7    .5    .0
002-005        7.6  33.8               160         .68   5.1   1.3    .0    .8    .0   5.8    .4    .3    .0
005-010        7.5  31.9               160         .78   5.7   1.4    .0    .9    .0   3.3    .1   3.3    .0
010-020        7.7  32.3               100        .500   3.4    .9    .0    .7    .0   3.7    .1    .7    .2
020-050                                           .200
050-100 7100   8.3                                .200                                                                NP
100-200 6500   8.3                                .200
100-200
000-005

------------------------------------------------------------------------------------------------------------------------
(A)  WHOLE SOIL, INCLUDING COURSE FRAGMENTS, CRUSHED TO PASS 2 MM SIEVE.
(B)  CLOD OF A11, A12, AND A13 FOR BULK DENSITY AND MOISTURE RETENTION.
(C)  ESTIMATE
(D)  1:2 SOIL WATER RATIO.
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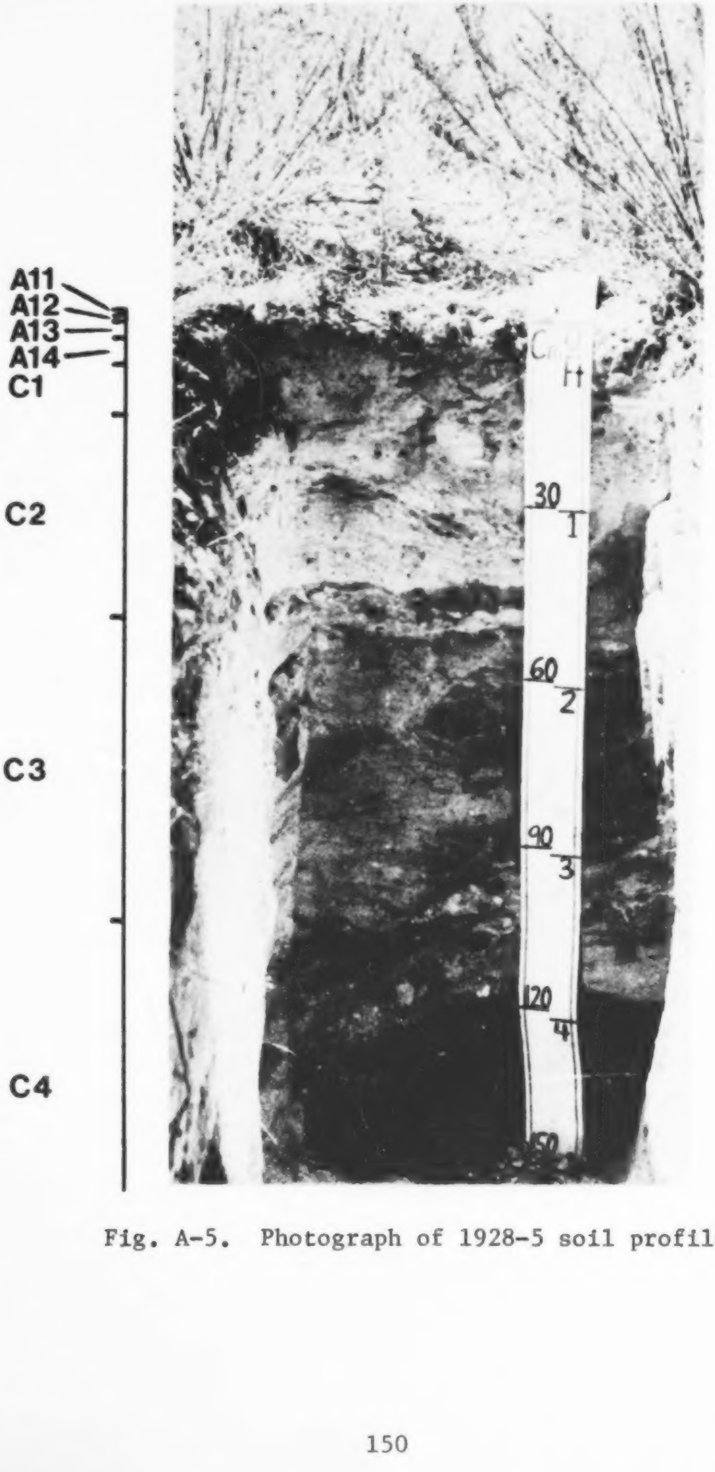
A11
A12
A13
A14
C1
C2
C3
C4
Cm
Ft
30
1
60
2
90
3
120
4
150

Fig. A-5. Photograph of 1928-5 soil profile.

Table A-11. Pedon description of Riedel-6 soil.

```
SOIL SERIES:                                  RIEDEL

SURVEY SAMPLE NO.:                            S76MT    173  6
LOCATION:           SE 1/4, NE 1/4, NE 1/4, SECT 3 T1N, R41E, 1 MI SE OF COLSTRIP, MT.
CLASSIFICATION:     USTIC    TORRIORTHENTS; LOAMY    , MIXED (CALCAREOUS)  , FRIGID   , SHALLOW

SITE NO.: 76  6     COUNTY:                   ELEVATION: 1042 METERS      MONTH SAMPLED: AUGUST
SLOPE:          4   CLASS:   NEARLY LEVEL     KIND:         CONCAVE       ASPECT:  NORTHEAST
AIR TEMPERATURE     ANNUAL: 46 DEGREES F      SUMMER: 68 DEGREES F        WINTER: 24 DEGREES F
SOIL TEMPERATURE    ANNUAL:    DEGREES F      SUMMER:    DEGREES F        WINTER:    DEGREES F
WATER TABLE:        DEPTH:     CM.            MONTHS:  AUGUST             KIND:  NO WATER TABLE
PRECIPITATION:      36  CM.                   CONTROL SECTION LIMITS --   UPPER: 025 CM  LOWER: 100 CM
PERMEABILITY:       MODERATELY RAPID          DRAINAGE CLASS:  WELL DRAINED
PHYSIOGRAPHY:       ROLLING OR HILLY UPLANDS                              STONINESS: CLASS 0
MICRORELIEF:        ON CREST OF HIGH POINT
VEGETATION:         GRASSES AND FORBS
PARENT MATERIAL:    SLIGHTLY    WEATHERED    RESIDUAL MATERIAL, LOCAL COLLUVIUM OR SOLIFLUCTATE
                    CALCAREOUS SANDSTONE

  HORIZON                                     PROFILE DESCRIPTION

 A  11                0 -   1 CM.  (  0 -   0 IN.)
                    BROWN    (10YR  5/3) CRUSHED  ;  SANDY LOAM   ;  DK. YELLOWISH BROWN (10YR  4/4)
                    CRUSHED MOIST    ;  WEAK TO MODERATE    MEDIUM  SUBANGULAR BLOCKY   STRUCTURE     ;
                    SOFT     , VERY FRIABLE     , NONSTICKY     , NONPLASTIC   ;  COMMON TO MANY
                    FINE    ROOTS   THROUGHOUT HORIZON   ;  MANY    FINE    IRREGULAR   PORES    ;
                    MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ;  MODERATELY ALKALINE PH= 8.4
                    (BROMTHYMOL BLUE)    ;  ARBITRARY   BOUNDARY   .

 A  12                1 -   2 CM.  (  0 -   1 IN.)
                    BROWN    (10YR  5/3) CRUSHED  ;  SANDY LOAM   ;  DK. YELLOWISH BROWN (10YR  4/4)
                    CRUSHED MOIST    ;  WEAK TO MODERATE    MEDIUM  SUBANGULAR BLOCKY   CRY STRUCTURE     ;
                    SOFT     , VERY FRIABLE     , NONSTICKY     , NONPLASTIC   ;  COMMON TO MANY
                    FINE    ROOTS   THROUGHOUT HORIZON   ;  MANY    FINE    IRREGULAR   PORES    ;
                    MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ;  MODERATELY ALKALINE PH= 8.4
                    (BROMTHYMOL BLUE)    ;  ARBITRARY   BOUNDARY   .

 A  13                2 -   5 CM.  (  1 -   2 IN.)
                    BROWN    (10YR  5/3) CRUSHED  ;  SANDY LOAM   ;  DK. YELLOWISH BROWN (10YR  4/4)
                    CRUSHED MOIST    ;  WEAK TO MODERATE    MEDIUM  SUBANGULAR BLOCKY   STRUCTURE     ;
                    SOFT     , VERY FRIABLE     , NONSTICKY     , NONPLASTIC   ;  COMMON TO MANY
                    FINE    ROOTS   THROUGHOUT HORIZON   ;  MANY    FINE    IRREGULAR   PORES    ;
                    MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ;  MODERATELY ALKALINE PH= 8.4
                    (BROMTHYMOL BLUE)    ;  ARBITRARY   BOUNDARY   .

 A  14                5 -  10 CM.  (  2 -   4 IN.)
                    BROWN    (10YR  5/3) CRUSHED  ;  SANDY LOAM   ;  DK. YELLOWISH BROWN (10YR  4/4)
                    CRUSHED MOIST    ;  WEAK TO MODERATE    MEDIUM  SUBANGULAR BLOCKY   STRUCTURE     ;
                    SOFT     , VERY FRIABLE     , NONSTICKY     , NONPLASTIC   ;  COMMON TO MANY
                    FINE    ROOTS   THROUGHOUT HORIZON   ;  MANY    FINE    IRREGULAR   PORES    ;
                    MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ;  MODERATELY ALKALINE PH= 8.4
                    (BROMTHYMOL BLUE)    ;  CLEAR    SMOOTH  BOUNDARY   .

 B  21               10 -  25 CM.  (  4 -  10 IN.)
                    LIGHT OLIVE BROWN    (2.5Y  5/4) CRUSHED  ;  SANDY LOAM   ;  DK. YELLOWISH BROWN
                    (10YR  4/4) CRUSHED MOIST    ;  WEAK TO MODERATE    MEDIUM  SUBANGULAR BLOCKY
                    STRUCTURE    ;  SOFT     , VERY FRIABLE     , NONSTICKY     , NONPLASTIC   ;
                    COMMON FINE    ROOTS   THROUGHOUT HORIZON   ;  MANY     FINE     IRREGULAR    PORES    ;
                    MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ;  MODERATELY ALKALINE PH= 8.4
                    (BROMTHYMOL BLUE)    ;  CLEAR    SMOOTH  BOUNDARY   .

 B  22               25 -  35 CM.  ( 10 -  14 IN.)
                    LIGHT OLIVE BROWN    (2.5Y  5/4) CRUSHED  ;  SANDY LOAM   ;  DK. YELLOWISH BROWN
                    (10YR  4/4) CRUSHED MOIST    ;  WEAK TO MODERATE    MEDIUM  SUBANGULAR BLOCKY
                    STRUCTURE    ;  SOFT     , VERY FRIABLE     , NONSTICKY     , NONPLASTIC   ;
                    COMMON  FINE    ROOTS   THROUGHOUT HORIZON   ;  MANY     FINE     IRREGULAR    PORES    ;
                    VIOLENTLY EFFERVESCENT  (HCL)   CONTINUOUS   ;  MODERATELY ALKALINE PH= 8.4
                    (BROMTHYMOL BLUE)    ;  CLEAR    WAVY     BOUNDARY   .

 C   1               35 -  50 CM.  ( 14 -  20 IN.)
                    LT. YELLOWISH BROWN (2.5Y  6/3) CRUSHED  ;  LOAMY SAND   ;  REDDISH BROWN   (2.5YR 5/4)
                    CRUSHED MOIST    ;  MODERATE     COARSE  PLATY   STRUCTURE    ;  SLIGHTLY HARD    ,
                    FRIABLE  ,  NONSTICKY    ,  NONPLASTIC   ;  FEW FINE    ROOTS   THROUGHOUT HORIZON   ;
                    MANY    FINE    IRREGULAR    PORES    ;  VIOLENTLY EFFERVESCENT   (HCL)   CONTINUOUS   ;
                    MODERATELY ALKALINE PH= 8.4 (BROMTHYMOL BLUE)    ;  ARBITRARY     BOUNDARY   .

 C   2               50 - 100 CM.  ( 20 -  39 IN.)
                    PALE BROWN  (10YR  6/3) CRUSHED  ;  LOAMY SAND   ;  YELLOWISH BROWN (10YR  5/4)
                    CRUSHED MOIST    ;  MODERATE    MEDIUM  PLATY   STRUCTURE    ;  SLIGHTLY HARD    ,
                    FRIABLE  ,  NONSTICKY    ,  NONPLASTIC   ;  FEW FINE    ROOTS   THROUGHOUT HORIZON   ;
                    MANY    FINE    IRREGULAR    PORES    ;  MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ;
                    MODERATELY ALKALINE PH= 8.4 (BROMTHYMOL BLUE)    ;  GRADUAL SMOOTH   BOUNDARY   .

 C   3              100 - 176 CM.  ( 39 -  69 IN.)
                    LT. YELLOWISH BROWN (10YR  6/4) CRUSHED  ;  LOAMY SAND   ;  YELLOWISH BROWN (10YR  5/4)
                    CRUSHED MOIST    ;  70  PERCENT SLIGHTLY HARD   LOAMY SAND  BROWNISH YELLOW (10YR  6/6)
                    CRUSHED STRATIFICATIONS    06    -  CM THICK )   ;  MASSIVE   ;  SLIGHTLY HARD    ,
                    FRIABLE  ,  NONSTICKY    ,  NONPLASTIC   ;  MANY    FINE    IRREGULAR   PORES    ;
                    MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ;  MODERATELY ALKALINE PH= 8.4
                    (BROMTHYMOL BLUE)    ;  NOT REACHED BOUNDARY   .

  REMARKS:          AUG 10, 1976 SOIL TEMP =22.0 C AT 50 CM.  SOIL TEMP AT 176 CM =18.5 C.  STRUCTUR
                    E OF C1 HORIZON IS RELATED TO BEDDING OF THE SANDSTONE BEDROCK.  STRATIFICATIONS
                     IN THE C2 ARE INHERITED FROM BEDROCK.  THE C3 HORIZON IS SIMILAR TO A PARALITHI
                    C CONTACT EXCEPT THAT IT IS PERMEABLE AND MAY HOLD AVAILABLE WATER.  HOWEVER, RO
                    OTS CANNOT PENETRATE.  THYMOL BLUE INDICATOR GIVES PH VALUES 0.5 TO 1.0 HIGHER T
                    HAN METER.
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Table A-12. Laboratory analyses of Riedel-6 soil.

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SOIL CLASSIFICATION-                                                          U. S. DEPARTMENT OF AGRICULTURE
                                                                              SOIL CONSERVATION SERVICE, MTSC
SERIES - - - - - - - -SERIES NOT DESIGNATED                                   NATIONAL SOIL SURVEY LABORATORY
                                                                              LINCOLN, NEBRASKA
SOIL NO - - - - - - - S76NT-087-6     COUNTY - - -  ROSEBUD

GENERAL METHODS- - -1A, 1B1B, 2A1, 2B               SAMPLE NOS. 76P0578-76P0587

-----------------------------------------------------------------------------------------------------------------
 DEPTH   HORIZON   (- - - - - - - - - - - - - - - PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B - - - - - - - - - )RATIO
                                       FINE ( - - - - - SAND - - - - - - )(- - -SILT- - - -) FAML  INTR  FINE  NON-  8D1
                    SAND  SILT  CLAY  CLAY  VCOS  CORS  MEDS  FNES  VFNS  COSI  FNSI  VFSI  TEXT  II    CLAY  CO3-  15-
                    2-    .05-  LT    LT    2-    1-    .5-   .25-  .10-  .05   .02   .005- SAND  .2-   TO    CLAY  BAR
                    .05   .002  .002  .0002 1     .5    .25   .10   .05   .02   .002  .002  2-.1  .02   CLAY        TO
  CM               (- - - - - - - - - - - - - - - - - - - PCT LT 2MM - - - - - - - - - - - - - - - - -) PCT   PCT  CLAY
-----------------------------------------------------------------------------------------------------------------
000-001  A11        76.4  15.0   8.6          .8   1.0   1.6  43.2  29.8   7.2   7.8         46.6                9   .62
001-002  A12        76.9  14.7   8.4          .6    .7   1.4  42.4  31.8   6.6   8.1         45.1                8   .49
002-005  A13        77.8  14.1   8.1          .3    .7   1.4  47.0  28.4   6.4   7.7         49.4                8   .49
005-010  A14        73.7  17.0   9.3          .4    .7   1.3  41.1  30.2   8.1   8.9         43.5                9   .46
010-025  B21        75.1  15.1   9.8          .3    .3    .8  39.0  34.7   7.7   7.4         40.4               10   .44
025-035  B22        77.9  12.9   9.2          .4    .4    .5  43.2  33.4   5.8   7.1         44.5                9   .45
035-050  C1         76.7  15.7   7.6          .1    .1    .4  40.9  35.2   7.5   8.2         41.5                8   .46
050-100  C2         85.0  10.5   4.5          .2    .1    .3  50.9  33.5   4.6   5.9         51.5                5   .51
100-176  C3         86.3   9.0   4.7          .0    .1    .9  53.7  31.6   3.3   5.7         54.7                5   .45
------   AB         73.4  15.6  11.0          .2    .4   5.4  55.6  11.8   8.2   7.4         61.6               11   .38

-----------------------------------------------------------------------------------------------------------------
DEPTH  (PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2)( BULK DENSITY )(- - - -WATER  CONTENT- - - -) CARBONATE (- -PH - -)
        VOL. (- - - - - - - - WEIGHT - - - - - - - -) 4A1D  4A1H  4D1    4B1C  4B1C  4B2   4C1        6E1B  3A1A  8C1A  8C1E
        GT    GT    75-20 20-5  5-2    LT    20-2  1/3-  OVEN COLE    1/10  1/3-  15-   WRD        LT    LT    1/1   1/2
        2     75                       .074  PCT   BAR   DRY          BAR   BAR   BAR   CM/        2     .002  H2O   CACL
  CM    PCT   PCT  (- - - PCT LT 75 - - - -) LT20  G/CC  G/CC         PCT   PCT   PCT   CM         PCT   PCT
-----------------------------------------------------------------------------------------------------------------
000-001    3     0     0     2     3            5  1.4 A                            5.3                 8         8.0   7.5
001-002    3     0     0     2     2            4  1.4 A                            4.1                 8         8.1   7.4
002-005    1     0     0     1     1            2  1.38  1.40  .005        10.6     4.0   .09           7         8.1   7.5
005-010   TR     0     0    TR     1            1  1.35  1.37  .005        16.5     4.3   .17           2         8.1   7.4
010-025    1     0     0     1     1            2  1.37  1.41  .010        13.5     4.3   .12           7    TR   8.1   7.5
025-035    2     0     0     2     2            4  1.4 A                            4.1                12    TR   8.3   7.6
035-050    1     0     0     1    TR            1  1.34  1.45  .026        14.9     3.5   .15          18    TR   8.4   7.7
050-100    0     0     0     0     0            0                                   2.3                17    TR   8.6   7.8
100-176   TR     0     0     0    TR           TR  1.61  1.63  .000         7.6     2.1   .09          15    TR   8.6   7.8
------     1     0     0     1     1            2  1.5 A                            4.2                TR    TR   8.3   7.6

-----------------------------------------------------------------------------------------------------------------
DEPTH (ORGANIC MATTER  ) IRON  PHOS  (- -EXTRACTABLE BASES 5B4A- -) ACTY   AL   (CAT EXCH) RATIO RATIO  CA  (BASE  SAT)
       6A1A  6B1A  C/N  6C2B        6N2E  6O2D  6P2B  6Q2B        6H1A  6G1E  5A3A  5A6A  8D1   8D3   5F1   5C3   5C1
       ORGN  NITG       EXT   TOTL  CA    MG    NA    K     SUM   BACL  KCL   EXTR  NHAC  NHAC  CA    SAT   EXTB  NHAC
       CARB             FE                                  EXTB  TEA   EXT   ACTY        TO    TO    NHAC  ACTY
  CM   PCT   PCT        PCT   PCT (- - - - - - - - - - - - MEQ / 100  G- - - - - - - - - - - - -) CLAY  MG    PCT   PCT   PCT
-----------------------------------------------------------------------------------------------------------------
000-001 1.08  .095   11                     2.1    TR    .4                          7.2   .84
001-002  .68  .068   10                     2.4    TR    .4                          6.5   .77
002-005  .90  .071   13                     2.6    .0    .3                          6.9   .85
005-010  .91  .086   11                     3.4    .0    .4                          8.3   .89
010-025  .85  .081   10                     3.4    .0    .4                          7.0   .71
025-035  .55  .058    9                     3.0    .0    .3                          5.3   .57
035-050  .40  .041   10                     3.0    .0    .2                          4.1   .54
050-100  .10  .016    6                     3.8    .0    .3                          3.1   .65
100-176  .04  .003   13                     3.8    .0    .1                          3.4   .72
------

-----------------------------------------------------------------------------------------------------------------
DEPTH  (SATURATED PASTE)  NA    NA    SALT  GYP  (- - - - - - - - - - SATURATION EXTRACT 8A1- - - - - - - - - ) ATTERBERG
        8F1  8C1B   8A    5D2   5E    8D5   6F1A  8A1A  6N1B  6O1B  6P1B  6Q1B  6I1A  6J1A  6K1C  6L1C  6M1C   4F1  4F2
        REST PH     H2O   ESP   SAR   TOTL        EC    CA    MG    NA    K     CO3   HCO3  CL    SO4   NO3    LQID PLST
        OHM-                          SOLD        MMHOS/                                                       LMIT INDX
  CM    CM          PCT   PCT         PPM   PCT   CM (- - - - - - - - - - - MEQ / LITER - - - - - - - - - - - -) PCT
-----------------------------------------------------------------------------------------------------------------
000-001          7.3  36.5              310         1.22  10.9   1.8    .1    .5    .0  10.6    .2    .6    .0
001-002          7.7  31.1              130          .59   5.1    .9    .1    .3    .0   4.6    .2    .4    .5
002-005                                             .208
005-010                                             .208
010-025                                             .208
025-035                                             .208
035-050                                             .208
050-100  7900    8.5                                .208
100-176  8700    8.6                                .208
------

-----------------------------------------------------------------------------------------------------------------
(A)  ESTIMATE
(B)  1:2 SOIL WATER RATIO
```

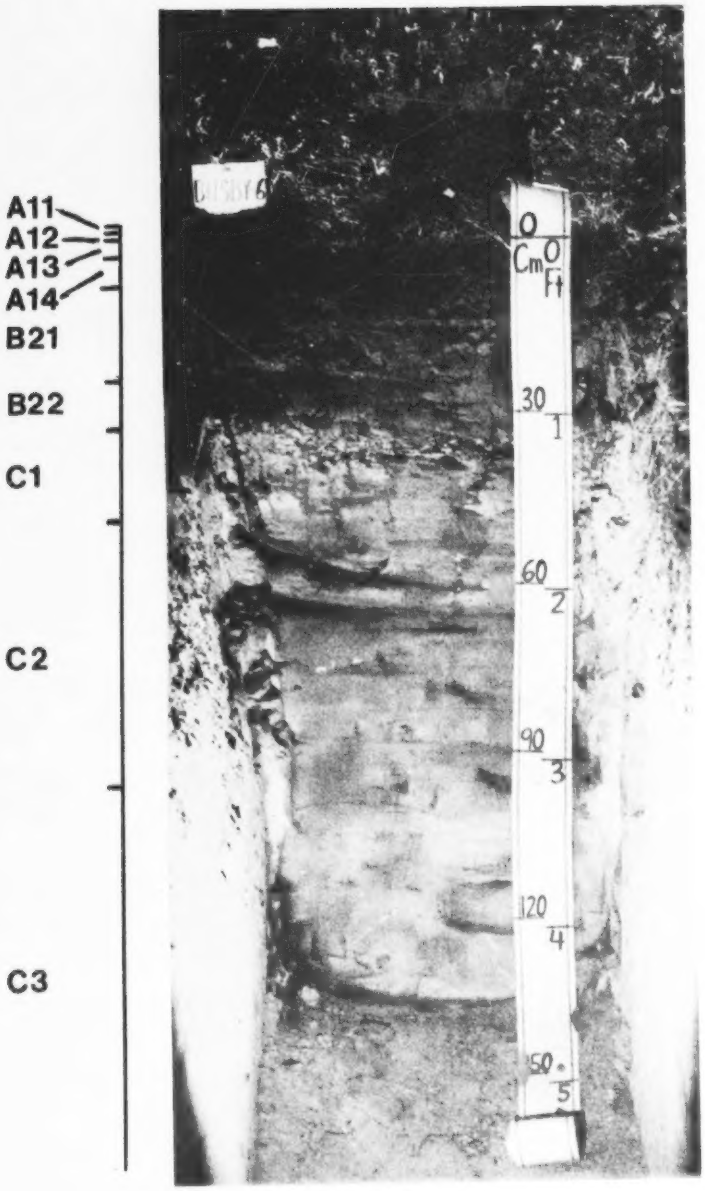
A11
A12
A13
A14
B21
B22
C1
C2
C3
0
Cm
0
Ft
30
1
60
2
90
3
120
4
150
5

Fig. A-6. Photograph of Riedel-6 soil profile.

Table A-13. Pedon description of 1928-7 soil.

```
SOIL SERIES:                              1924 SPOILS

SURVEY SAMPLE NO.:                        C      173  7
LOCATION:          SE 1/4, SE 1/4, NE 1/4, SECT 3 T1N R41, 1 MI SE OF COLSTRIP, MT
CLASSIFICATION:

SITE NO.:  2  7     COMPLETE SEE REMARKS     ELEVATION: 1030 METERS      MONTH SAMPLED: AUGUST
SLOPE:         6    CLASS:  NEARLY LEVEL     WIND:        PLANE          ASPECT:  WEST
AIR TEMPERATURE:    ANNUAL: 46 DEGREES F     SUMMER: 68 DEGREES F        WINTER: 24 DEGREES F
SOIL TEMPERATURE:   ANNUAL:    DEGREES F     SUMMER:    DEGREES F        WINTER:    DEGREES F
WATER TABLE:        DEPTH:      CM.          MONTH:  AUGUST              KIND:  NO WATER TABLE
PRECIPITATION:        [illegible] CM.        CONTROL SECTION LIMITS --   UPPER: 025 CM  LOWER: 100 CM
PERMEABILITY:       RAPID                    DRAINAGE CLASS:  SOMEWHAT EXCESSIVELY DRAINED
PHYSIOGRAPHY:       ROLLING OR HILLY UPLANDS                             STONINESS: CLASS 0
VEGETATION:         GRASSES AND FORBS AND SHRUBS
PARENT MATERIAL:    SLIGHTLY   WEATHERED   UNCONSOLIDATED MINERAL SEDIMENTS
                    CALCAREOUS SANDSTONE

   HORIZON                                PROFILE DESCRIPTION

 A  11              0 -   1 CM.  (  0 -   0 IN.)
                   BROWN   (10YR  5/3) CRUSHED  ;  SANDY LOAM   ;  BROWN   (10YR  4/3) CRUSHED MOIST   ;
                   MASSIVE  ;  SOFT     ,  VERY FRIABLE     ,  NONSTICKY    ,  NONPLASTIC   ;  MANY
                   FINE    ROOTS   THROUGHOUT HORIZON   ;  MANY    FINE    IRREGULAR   PORES    ;
                   MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ;  MODERATELY ALKALINE PH- 8.2
                   (BROMTHYMOL BLUE)   ;  ARBITRARY   BOUNDARY   .

 A  12              1 -   2 CM.  (  0 -   1 IN.)
                   PALE BROWN  (10YR  6/3) CRUSHED  ;  SANDY LOAM   ;  BROWN   (10YR  4/3) CRUSHED
                   MOIST    ;  WEAK TO MODERATE    FINE    PLATY   STRUCTURE    ;  LOOSE    ,  LOOSE    ,
                   NONSTICKY    ,  NONPLASTIC   ;  MANY    FINE    ROOTS   THROUGHOUT HORIZON   ;
                   MANY    FINE    IRREGULAR   PORES    ;  MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ;
                   MODERATELY ALKALINE PH- [illegible] (BROMTHYMOL BLUE)    ;  ARBITRARY   BOUNDARY   .

 A  13              2 -   5 CM.  (  1 -   2 IN.)
                   PALE BROWN  (10YR  6/3) CRUSHED  ;  SANDY LOAM   ;  BROWN   (10YR  4/3) CRUSHED
                   MOIST    ;  WEAK TO MODERATE    COARSE  PLATY   STRUCTURE    ;  SOFT     ,
                   VERY FRIABLE     ,  NONSTICKY    ,  NONPLASTIC   ;  MANY    FINE    ROOTS
                   THROUGHOUT HORIZON   ;  MANY    FINE    IRREGULAR   PORES    ;
                   MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ;  MODERATELY ALKALINE PH- 8.4
                   (BROMTHYMOL BLUE)   ;  ARBITRARY   BOUNDARY   .

 A  14              5 -  11 CM.  (  2 -   4 IN.)
                   PALE BROWN  (10YR  6/3) CRUSHED  ;  SANDY LOAM   ;  BROWN   (10YR  4/3) CRUSHED
                   MOIST    ,  WEAK TO MODERATE    COARSE  PLATY   STRUCTURE    ;  SOFT     ,
                   VERY FRIABLE     ,  NONSTICKY    ,  NONPLASTIC   ;  MANY    FINE    ROOTS
                   THROUGHOUT HORIZON   ;  MANY    FINE    IRREGULAR   PORES    ;
                   MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ;  STRONGLY ALKALINE   PH- 8.6
                   (BROMTHYMOL BLUE)   ;  ABRUPT  WAVY    BOUNDARY   .

 C   1             11 -  22 CM.  (  4 -   8 IN.)
                   PALE RED    (2.5YR 7/2) CRUSHED  ;  SANDY LOAM   ;  GRAYISH BROWN   (10YR  5/2)
                   CRUSHED MOIST    ;  PALE BROWN  (10YR  6/3) CRUSHED  ;  YELLOWISH BROWN (10YR  5/4)
                   CRUSHED MOIST    ;  FEW MEDIUM  PROMINENT   BROWNISH YELLOW (10YR  6/6) CRUSHED
                   MOTTLES  ;  MODERATE    MEDIUM & COARSE    PLATY   STRUCTURE    ;  SOFT     ,
                   VERY FRIABLE     ,  NONSTICKY    ,  NONPLASTIC   ;  COMMON TO MANY  FINE    ROOTS
                   THROUGHOUT HORIZON   ;  MANY    FINE    IRREGULAR   PORES    ;
                   VIOLENTLY EFFERVESCENT  (HCL)   CONTINUOUS   ;  STRONGLY ALKALINE   PH- 8.6
                   (BROMTHYMOL BLUE)   ;  ABRUPT  WAVY    BOUNDARY   .

 C   2             22 -  50 CM.  (  8 -  20 IN.)
                   PALE BROWN  (10YR  6/3) CRUSHED  ;  SANDY LOAM   ;  YELLOWISH BROWN (10YR  5/4)
                   CRUSHED MOIST    ;  PALE RED    (2.5YR 7/2) CRUSHED  ;  REDDISH BROWN   (2.5YR 5/3)
                   CRUSHED MOIST    ;  10  PERCENT VERY HARD   SANDY LOAM  V DK GRAYISH BROWN  (10YR  3/2)
                   CRUSHED MOIST   POCKETS OR CONTRASTING MATERIAL(50   -  CM THICK )   ;  MASSIVE  ;
                   SLIGHTLY HARD    ,  FRIABLE  ,  NONSTICKY    ,  NONPLASTIC   ;  FEW FINE    ROOTS
                   THROUGHOUT HORIZON   ;  MANY    FINE    IRREGULAR   PORES    ;  FEW SANDSTONE
                   FRAGMENTS   >2 CM    ;  VIOLENTLY EFFERVESCENT  (HCL)   CONTINUOUS   ;
                   STRONGLY ALKALINE   PH- 8.6 (BROMTHYMOL BLUE)   ;  ABRUPT  WAVY    BOUNDARY   .

 C   3             50 - 100 CM.  ( 20 -  39 IN.)
                   PALE BROWN  (10YR  6/3) CRUSHED  ;  SANDY LOAM   ;  YELLOWISH BROWN (10YR  5/4)
                   CRUSHED MOIST    ;  10  PERCENT VERY HARD   SANDY LOAM  BROWN   (10YR  4/3) CRUSHED
                   POCKETS OR CONTRASTING MATERIAL(20   -  CM THICK )   ;  MASSIVE  ;  SLIGHTLY HARD    ,
                   FRIABLE  ,  NONSTICKY    ,  NONPLASTIC   ;  FEW FINE    ROOTS   THROUGHOUT HORIZON   ;
                   MANY    FINE    IRREGULAR   PORES    ;  VIOLENTLY EFFERVESCENT  (HCL)   CONTINUOUS   ;
                   STRONGLY ALKALINE   PH- 8.6 (BROMTHYMOL BLUE)   ;  ARBITRARY   BOUNDARY   .

 C   4            100 - 200 CM.  ( 39 -  79 IN.)
                   LT. YELLOWISH BROWN (10YR  6/4) CRUSHED  ;  SANDY LOAM   ;  YELLOWISH BROWN (10YR  5/4)
                   CRUSHED MOIST    ;  MASSIVE  ;  SLIGHTLY HARD    ,  FRIABLE  ,  NONSTICKY    ,
                   NONPLASTIC   ;  FEW FINE    ROOTS   THROUGHOUT HORIZON   ;  MANY    FINE
                   IRREGULAR   PORES    ;  VIOLENTLY EFFERVESCENT  (HCL)   CONTINUOUS   ;
                   STRONGLY ALKALINE   PH- 8.8 (BROMTHYMOL BLUE)   ;  NOT REACHED BOUNDARY   .

   REMARKS:        STRIP-MINE SPOILS NEAR COLSTRIP, MONTANA LEVELED IN 1924.  AUG 16, 1976 SOIL TEMP
                   P. [illegible] F AT 50 CM.  COMMON POCKETS OF INHERITED A1 MATERIAL WHICH IS SLIGHTLY
                   HEAVIER IN TEXTURE.  ROOTS PROLIFERATE IN BURIED A1 POCKETS.  GRAY SANDSTONE IN
                   C1 AND C2 HAS HARD CONSISTENCE. 1-4% SHALE AND SILTSTONE IN C3.  INTERMITTENT CO
                   NVEX-UPWARDS BAND OF A1 MATERIAL 50 CM WIDE AND 15 CM HIGH OCCUR AS DEPOSITIONAL
                   FEATURES.  PROMINENT DIAGONAL SHEAR PLANES PARALLEL TO THE OUTSIDE EDGE OF THE
                   SPOIL PLATFORM MAY REPRESENT THE FORMER EXTENT OF THE SPOIL PLATFORM DURING DEPO
                   SITION.  PLATY STRUCTURE NEAR THE SURFACE MAY BE DUE TO COMPACTION BY HORSES HAU
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Table A-14. Laboratory analyses of 1928-7 soil.

```
SOIL CLASSIFICATION-                                                          U. S. DEPARTMENT OF AGRICULTURE
                                                                              SOIL CONSERVATION SERVICE. MTSC
SERIES - - - - - - -SERIES NOT DESIGNATED                                     NATIONAL SOIL SURVEY LABORATORY
                                                                              LINCOLN, NEBRASKA
SOIL NO - - - - - - S76MT-087-7     COUNTY - - -  ROSEBUD

GENERAL METHODS- - -1A, 1B1B, 2A1, 2B            SAMPLE NOS. 76P0588-76P0596

-------------------------------------------------------------------------------------------------------------------
 DEPTH   HORIZON   (- - - - - - - - - - - - - - - PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B - - - - - - - - - )RATIO
                                     FINE ( - - - - - SAND - - - - - - )(- - -SILT- - - -) FAML  INTR  FINE  NON-   8D1
                   SAND  SILT  CLAY  CLAY  VCOS  CORS  MEDS  FNES  VFNS  COSI  FNSI  VFSI  TEXT  II    CLAY  CO3-   15-
                   2-    .05-  LT    LT    2-    1-    .5-   .25-  .10-  .05   .02   .005- SAND  .2-   TO    CLAY   BAR
                   .05   .002  .002  .0002 1     .5    .25   .10   .05   .02   .002  .002  2-.1  .02   CLAY          TO
  CM               (- - - - - - - - - - - - - - - - - - PCT LT 2MM - - - - - - - - - - - - - - - - - -) PCT   PCT   CLAY
-------------------------------------------------------------------------------------------------------------------
000-001   A11      80.5  12.4   7.1           .9   1.4   4.9  57.0  16.3   5.3   7.1         64.2                 7    .66
001-002   A12      82.1  11.5   6.4           .2    .4   3.0  61.7  16.8   4.9   6.6         65.3                 6    .52
002-005   A13      81.7  10.2   8.1           .2    .5   3.3  61.2  16.5   4.7   5.5         65.2                 8    .40
005-010   A14      78.3  14.8   6.9           .9    .4   4.0  59.2  13.8   7.1   7.7         64.5                 7    .48
010-020   C1       81.3  12.5   6.2           .2    .4   3.1  62.4  15.2   5.0   7.5         66.1                 6    .50
020-050   C2       80.3  12.3   7.4           .2    .4   3.1  62.9  13.7   5.2   7.1         66.6                 7    .47
050-100   C3       75.0  14.9  10.1           .2    .4   4.2  54.8  15.4   6.7   8.2         59.6                10    .41
100-200   C4       66.4  20.4  13.2           .7    .5   3.3  45.8  16.1  10.4  10.0         50.3                13    .36
--------  AB

-------------------------------------------------------------------------------------------------------------------
DEPTH  (PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2)(  BULK DENSITY  )(- - - -WATER  CONTENT- - - -) CARBONATE  (- -PH - -)
       VOL. (- - - - - - - WEIGHT - - - - - - - -) 4A1D  4A1H  4D1    4B1C  4B1C  4B2   4C1         6E1B  3A1A  8C1A  8C1E
       GT    GT    75-20 20-5  5-2    LT   20-2   1/3-  OVEN  COLE   1/10  1/3-  15-   WRD         LT    LT    1/1   1/2
       2     75                       .074 PCT    BAR   DRY          BAR   BAR   BAR   CM/         2     .002  H2O   CACL
 CM    PCT   PCT   (- - - PCT LT 75 - - - ) LT20  G/CC  G/CC         PCT   PCT   PCT   CM          PCT   PCT
-------------------------------------------------------------------------------------------------------------------
000-001  TR    0     0    TR     1           1   1.3 A                         4.7                  8    TR   7.5   7.2
001-002  TR    0     0    TR    TR          TR   1.4 A                         3.3                  8    TR   7.9   7.3
002-005  TR    0     0     1    TR           1   1.52  1.54  .005         9.8  3.2   .10            8    TR   7.8   7.3
005-010  TR    0     0     1    TR           1   1.5 A                         3.3                  9    TR   8.1   7.4
010-020   1    0     0    TR     1           1   1.61  1.63  .004        10.8  3.1   .12            9    TR   8.1   7.5
020-050  TR    0     0    TR     1           1   1.4 A                         3.5                  9    TR   8.4   7.7
050-100  TR    0     0    TR    TR          TR   1.25  1.47  .057         8.7  4.1   .06            9    TR   8.5   7.8
100-200  TR    0     0     1    TR           1   1.2 A                         4.8                  5    TR   8.4   7.8
-------- TR    0     0     1    TR           1   1.5 A                         5.6                 TR         8.2   7.7

-------------------------------------------------------------------------------------------------------------------
DEPTH (ORGANIC MATTER  ) IRON  PHOS  (- -EXTRACTABLE BASES 5B4A- -) ACTY   AL    (CAT EXCH) RATIO RATIO  CA   (BASE SAT)
       6A1A  6B1A  C/N  6C2B         6N2E  6O2D  6P2B  6Q2B        6H1A  6G1E  5A3A  5A6A  8D1   8D3    5F1  5C3   5C1
       ORGN  NITG       EXT   TOTL   CA    MG    NA    K     SUM   BACL  KCL   EXTB  NHAC  NHAC  CA     SAT  EXTB  NHAC
       CARB             FE                                   EXTB  TEA   EXT   ACTY        TO    TO     NHAC ACTY
  CM   PCT   PCT        PCT   PCT (- - - - - - - - - - - -MEQ / 100  G- - - - - - - - - - -) CLAY  MG     PCT  PCT   PCT
-------------------------------------------------------------------------------------------------------------------
000-001  2.01  .167  12                2.8   TR    .7                                 7.7  1.08
001-002  1.10  .069  16                2.4   .0    .4                                 5.7   .89
002-005   .73  .054  14                2.4   .0    .2                                 5.3   .65
005-010   .72  .048  15                2.6   .0    .3                                 5.3   .77
010-020   .38  .031  12                2.7   .0    .2                                 4.2   .68
020-050   .24  .024  10                3.8   .0    .2                                 4.4   .59
050-100   .15  .016   9                6.9   .0    .3                                 5.3   .52
100-200   .42  .045   9                8.2   TR    .3                                 7.6   .58
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-------------------------------------------------------------------------------------------------------------------
DEPTH   (SATURATED PASTE)  NA    NA    SALT  GYP  (- - - - - - - - - - SATURATION EXTRACT 8A1- - - - - - - - - ) ATTERBERG
         8E1   8C1B  8A    5D2   5E    8D5   6F1A  8A1A  6N1B  6O1B  6P1B  6Q1B  6I1A  6J1A  6K1C  6L1C  6M1C   4F1  4F2
         REST  PH    H2O   ESP   SAR   TOTL        EC    CA    MG    NA    K     CO3   HCO3  CL    SO4   NO3    LQID PLST
         OHM-                          SOLU        MMHOS/                                                       LMIT INDX
  CM     CM          PCT   PCT         PPM   PCT   CM  (- - - - - - - - - - MEQ / LITER - - - - - - - - - - - -) PCT
-------------------------------------------------------------------------------------------------------------------
000-001        6.8  45.9               1000    0   2.67  23.4   7.6    .1   4.2    .0  29.1    .6    .9    .0
001-002        7.6  33.8                220         .90   7.3   1.8    .0   1.0    .0   8.3    .2    .4    .0
002-005        7.7  31.7                130         .58   4.6   1.1    .0    .5    .0   4.8    .2    .2    .0
005-010        7.8  30.6                100         .48   3.7    .8    .0    .4    .0   3.6    .1    .2    .0
010-020        7.7  29.7                200         .95   7.9   1.8    .0    .6    .0   2.5    .1   6.7    .0
020-050                                            .208
050-100  5900  8.3                                 .208                                                             NP
100-200  4900  8.0  27.3                 90         .47   1.5   3.2    .3    .1    .0   1.2    .1    .7    .6
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(A)  ESTIMATE
(B)  1:2 SOIL WATER RATIO
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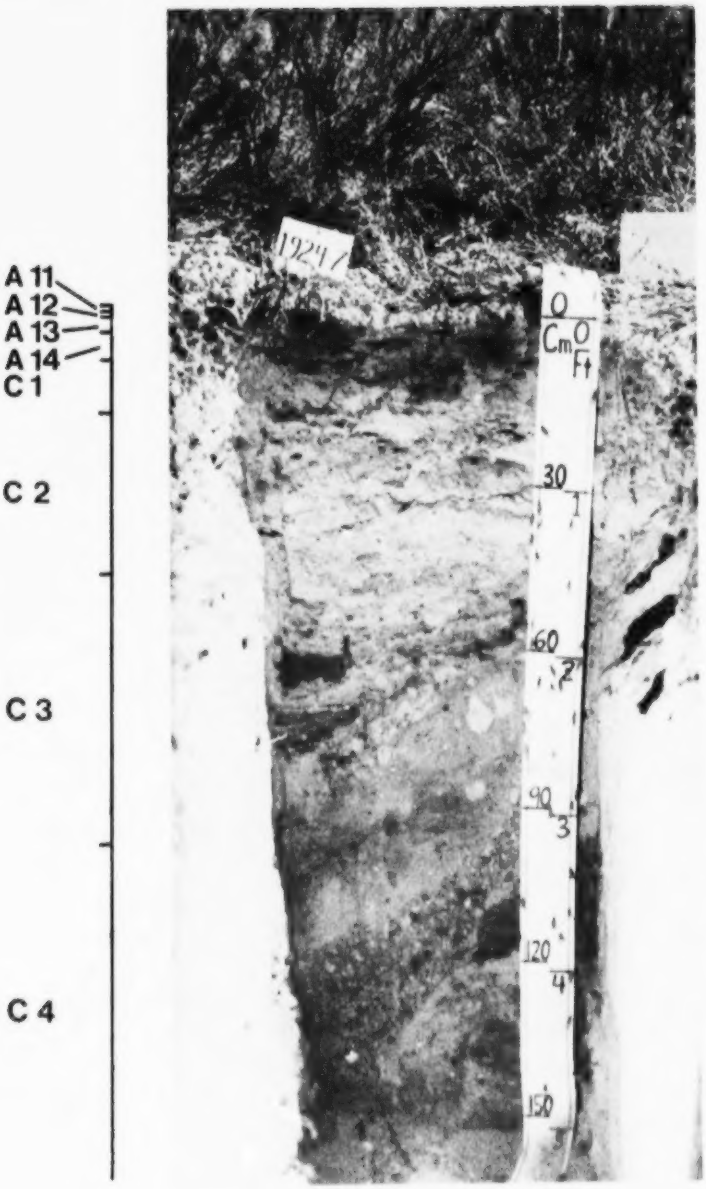
A 11
A 12
A 13
A 14
C 1
C 2
C 3
C 4
1924 7
0
Cm
0
Ft
30
1
60
2
90
3
120
4
150
5

Fig. A-7. Photograph of 1928-7 soil profile.

Table A-15. Pedon description of Chinook-8 soil.

```
SOIL SERIES:                               CHINOOK

SURVEY SAMPLE NO.:                         [illegible]   173  8
LOCATION:            NW 1/4, NE 1/4, NW 1/4, SECT 7 T1N, R41E, 3 MI SE OF COLSTRIP, MT.
CLASSIFICATION:      ARIDIC   HAPLOBOROLLS  COARSE-LOAMY , MIXED

SITE NO.:            COUNTY:                 ELEVATION: 1015 METERS        MONTH SAMPLED: AUGUST
SLOPE:         3     CLASS:   STRONGLY SLOPING  KIND:        CONCAVE       ASPECT:  SOUTHWEST
AIR TEMPERATURE:     ANNUAL: 47 DEGREES F    SUMMER: 68 DEGREES F          WINTER: 24 DEGREES F
SOIL TEMPERATURE:    ANNUAL:    DEGREES F    SUMMER:    DEGREES F          WINTER:    DEGREES F
WATER TABLE:         DEPTH:     CM.          MONTH:  AUGUST                KIND:  NO WATER TABLE
PRECIPITATION:       40 CM.                  CONTROL SECTION LIMITS --     UPPER: 025 CM  LOWER: 100 CM
PERMEABILITY:        MODERATELY RAPID        DRAINAGE CLASS:  WELL DRAINED
PHYSIOGRAPHY:        ROLLING OF HILLY UPLANDS                              STONINESS: CLASS 0
MICRORELIEF:         ON SLOPE
VEGETATION:          GRASSES AND FORBS
PARENT MATERIAL:     SLIGHTLY   WEATHERED   RESIDUAL MATERIAL, LOCAL COLLUVIUM OR SOLIFLUCTATE
                     CALCAREOUS SANDSTONE

                                       PROFILE DESCRIPTION
   HORIZON

   A  11             0 -   1 CM.  (  0 -   0 IN.)
                     GRAYISH BROWN   (10YR  5/2) CRUSHED  ;  SANDY LOAM   ;  V DK GRAYISH BROWN  (10YR  3/2)
                     CRUSHED MOIST    ;  10  PERCENT SOFT    SANDY LOAM  GRAYISH BROWN   (10YR  5/2)
                     CRUSHED KROTOVINAS 15    -  CM THICK )   ;  MODERATE    COARSE  PLATY   STRUCTURE    ;
                     SOFT     ,  VERY FRIABLE     ,  NONSTICKY    ,  NONPLASTIC   ;  COMMON  FINE
                     ROOTS   THROUGHOUT HORIZON   ;  MANY     FINE     IRREGULAR   PORES    ;
                     NONCALCAREOUS   (HCL)   DISCONTINUOUS    ;  MODERATELY ALKALINE PH- 8.0
                     (BROMTHYMOL BLUE)    ;  ARBITRARY   BOUNDARY   .

   A  12             1 -   2 CM.  (  0 -   1 IN.)
                     BROWN   (10YR  5/3) CRUSHED  ;  SANDY LOAM   ;  V DK GRAYISH BROWN  (10YR  3/2)
                     MOIST    ;  10  PERCENT SOFT    SANDY LOAM  VERY DARK GRAY  (10YR  3/1) EXTERIOR
                     KROTOVINAS 15    -  CM THICK )   ;  MODERATE    COARSE  PLATY   STRUCTURE    ;
                     SOFT     ,  VERY FRIABLE     ,  NONSTICKY    ,  NONPLASTIC   ;  COMMON  FINE
                     ROOTS   THROUGHOUT HORIZON   ;  MANY     FINE     IRREGULAR   PORES    ,  MANY
                     PORES    ;  NONCALCAREOUS   (HCL)   CONTINUOUS   ;  MODERATELY ALKALINE PH- 8.0
                     (BROMTHYMOL BLUE)    ;  ARBITRARY   BOUNDARY   .

   A  13             2 -   5 CM.  (  1 -   2 IN.)
                     GRAYISH BROWN   (10YR  5/2) CRUSHED  ;  SANDY LOAM   ;  V DK GRAYISH BROWN  (10YR  3/2)
                     CRUSHED MOIST    ;  10  PERCENT SOFT    SANDY LOAM  GRAYISH BROWN   (10YR  5/2)
                     CRUSHED KROTOVINAS 15    -  CM THICK )   ;  MODERATE    COARSE  PLATY   STRUCTURE    ;
                     SOFT     ,  VERY FRIABLE     ,  NONSTICKY    ,  NONPLASTIC   ;  COMMON  FINE
                     ROOTS   THROUGHOUT HORIZON   ;  MANY     FINE     IRREGULAR   PORES    ;
                     NONCALCAREOUS   (HCL)   CONTINUOUS    ;  MODERATELY ALKALINE PH- 8.0
                     (BROMTHYMOL BLUE)    ;  ABRUPT  WAVY    BOUNDARY   .

   A  14             5 -  10 CM.  (  2 -   4 IN.)
                     BROWN    (10YR  5/3) CRUSHED  ;  SANDY LOAM   ;  DARK BROWN  (10YR  3/3) CRUSHED
                     MOIST    ;  10  PERCENT SOFT    SANDY LOAM  BROWN   (10YR  5/3) CRUSHED KROTOVINAS 15
                      -  CM THICK )   ;  MODERATE    COARSE  PLATY   STRUCTURE    ;  SLIGHTLY HARD    ,
                     NONSTICKY    ,  VERY FRIABLE     ,  NONPLASTIC   ;  COMMON  FINE    ROOTS
                     THROUGHOUT HORIZON   ;  MANY     FINE     IRREGULAR   PORES    ;  NONCALCAREOUS
                     (HCL)   CONTINUOUS   ;  MODERATELY ALKALINE PH- 8.0 (BROMTHYMOL BLUE)    ;  ABRUPT
                     WAVY     BOUNDARY   .

   B  21             10 -  25 CM.  (  4 -  10 IN.)
                     YELLOWISH BROWN (10YR  5/4) CRUSHED  ;  SANDY LOAM   ;  BROWN    (10YR  4/3) CRUSHED
                     MOIST    ;  15  PERCENT SOFT    SANDY LOAM  YELLOWISH BROWN (10YR  5/4) CRUSHED
                     KROTOVINAS 15    -  CM THICK )   ;  VERY WEAK   COARSE  PRISMATIC   STRUCTURE   AND
                     WEAK     COARSE   SUBANGULAR BLOCKY   ;  HARD      ,  VERY FRIABLE     ,  NONSTICKY    ,
                     NONPLASTIC   ;  COMMON  FINE    ROOTS   THROUGHOUT HORIZON   ;  MANY     FINE
                     IRREGULAR   PORES    ;  NONCALCAREOUS   (HCL)   CONTINUOUS   ;  MODERATELY ALKALINE
                     PH- 8.0 (BROMTHYMOL BLUE)    ;  CLEAR    WAVY     BOUNDARY   .

   B  22             25 -  50 CM.  ( 10 -  20 IN.)
                     YELLOWISH BROWN (10YR  5/4) CRUSHED  ;  SANDY LOAM   ;  DK. YELLOWISH BROWN (10YR  4/4)
                     CRUSHED MOIST    ;  10  PERCENT SOFT    SANDY LOAM  YELLOWISH BROWN (10YR  5/4)
                     CRUSHED KROTOVINAS 15    -  CM THICK )   ;  VERY WEAK   COARSE  PRISMATIC
                     STRUCTURE   AND WEAK    COARSE   SUBANGULAR BLOCKY   ;  HARD      ,  VERY FRIABLE     ,
                     NONSTICKY    ,  NONPLASTIC   ;  COMMON  FINE    ROOTS   THROUGHOUT HORIZON   ;
                     MANY     FINE     IRREGULAR   PORES    ;  NONCALCAREOUS   (HCL)   DISCONTINUOUS    ;
                     MODERATELY ALKALINE PH- 8.0 (BROMTHYMOL BLUE)    ;  ABRUPT  BROKEN  BOUNDARY   .

   C  1CA            50 - 100 CM.  ( 20 -  39 IN.)
                     PALE BROWN   (10YR  6/3) CRUSHED  ;  SANDY LOAM   ;  YELLOWISH BROWN (10YR  5/4)
                     CRUSHED MOIST    ;  VERY WEAK   COARSE   SUBANGULAR BLOCKY   STRUCTURE    ;  HARD      ,
                     VERY FRIABLE     ,  NONSTICKY    ,  NONPLASTIC   ;  FEW TO COMMON   FINE    ROOTS
                     THROUGHOUT HORIZON   ;  MANY     FINE     IRREGULAR   PORES    ,  COMMON  FINE
                     TUBULAR PORES    ;  COMMON  SOFT    THREAD-LIKE MASSES OF LIME    ;
                     MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ;  STRONGLY ALKALINE   PH- 8.6
                     (BROMTHYMOL BLUE)    ;  GRADUAL SMOOTH  BOUNDARY   .

   C  2CA            100 - 150 CM.  ( 39 -  59 IN.)
                     VERY PALE BROWN (10YR  7/3) CRUSHED  ;  SANDY LOAM   ;  YELLOWISH BROWN (10YR  5/4)
                     CRUSHED MOIST    ;  VERY WEAK   COARSE   SUBANGULAR BLOCKY   STRUCTURE    ;  HARD      ,
                     VERY FRIABLE     ,  NONSTICKY    ,  NONPLASTIC   ;  FEW FINE    ROOTS
                     THROUGHOUT HORIZON   ;  MANY     FINE     TUBULAR PORES    ;  COMMON  SOFT
                     THREAD-LIKE MASSES OF LIME    ;  MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ;
                     STRONGLY ALKALINE   PH- 8.6 (BROMTHYMOL BLUE)    ;  DIFFUSE SMOOTH  BOUNDARY   .

   C  3              150 - 200 CM.  ( 59 -  79 IN.)
                     VERY PALE BROWN (10YR  7/3) CRUSHED  ;  SANDY LOAM   ;  YELLOWISH BROWN (10YR  5/4)
                     CRUSHED MOIST    ;  MASSIVE   ;  HARD      ,  VERY FRIABLE     ,  NONSTICKY    ,
                     NONPLASTIC   ;  FEW FINE    ROOTS   THROUGHOUT HORIZON   ;  MANY     FINE
                     IRREGULAR   PORES    ;  MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ;
                     MODERATELY ALKALINE PH- 8.4 (BROMTHYMOL BLUE)    ;  NOT REACHED BOUNDARY   .

   REMARKS:          [illegible] 1974  SOIL TEMP =22.0 C AT 50 CM.  MEDIUM TRANSECTS AT 1 FOOT SPACINGS AT
                     [illegible] TO 1.5 METERS.
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Table A-16. Laboratory analyses of Chinook-8 soil.

SOIL CLASSIFICATION-ARIDIC HAPLOBOROLL
COARSE-LOAMY, MIXED
SERIES - - - - - - - -CHINOOK

SOIL NO - - - - - - - S76MT-087-8   COUNTY - - - ROSEBUD

GENERAL METHODS- - -1A, 1B1B, 2A1, 2B   SAMPLE NOS. 76P0597-76P0605

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, MTSC
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA

DEPTH	HORIZON	PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B				SAND					SILT							RATIO
CM		SAND 2- .05	SILT .05- .002	CLAY LT .002	FINE CLAY LT .0002	VCOS 2- 1	CORS 1- .5	MEDS .5- .25	FNES .25- .10	VFNS .10- .05	COSI .05 .02	FNSI .02 .002	VFSI .005- .002	FAML TEXT SAND 2-.1	INTR II .2- .02	FINE CLAY TO CLAY PCT	NON- CO3- CLAY PCT	8D1 15- BAR TO CLAY
		PCT LT 2MM																
000-001	A11	81.7	12.2	6.1		.7	1.4	7.0	60.3	12.3	6.1	6.1		69.4				.72
001-002	A12	83.8	10.6	5.6		.7	1.1	6.5	63.5	12.0	5.7	4.9		71.8				.82
002-005	A13	82.5	10.7	6.8		.6	.7	5.4	64.2	11.6	5.1	5.6		70.9				.50
005-010	A14	81.9	9.7	8.4		.1	.4	4.9	65.8	10.7	4.7	5.0		71.2				.44
010-025	B21	80.8	10.7	8.5		TR	.2	5.0	64.0	11.6	6.0	4.7		69.2				.47
025-050	B22	78.0	9.4	12.6		.1	.2	4.1	61.6	12.0	5.9	3.5		66.0				.36
050-100	C1CA	78.7	10.4	10.9		.2	.2	3.8	50.2	14.3	5.6	4.8		64.4				.38
100-150	C2CA	65.4	19.6	15.0		TR	.4	2.8	47.4	14.8	10.1	9.5		50.6				.37
150-200	C3	74.2	14.5	11.3		.1	.2	2.7	50.9	20.3	10.6	3.9		53.9				.36

DEPTH	PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2							BULK DENSITY			WATER CONTENT				CARBONATE		PH	
	VOL.	WEIGHT																
CM	GT 2 PCT	GT 75 PCT	75-20	20-5	5-2	LT .074	20-2 PCT LT20	4A1D 1/3- BAR G/CC	4A1H OVEN DRY G/CC	4D1 COLE	4B1C 1/10 BAR PCT	4B1C 1/3- BAR PCT	4B2 15- BAR PCT	4C1 WRD CM/ CM	6E1B LT 2 PCT	3A1A LT .002 PCT	8C1A 1/1 H2O	8C1E 1/2 CACL
			PCT LT 75															
000-001	0	0	0	0	0		0						4.4		TR		7.4	7.0
001-002	TR	0	0	TR	TR		TR	1.4 A					4.6		TR		7.5	6.9
002-005	TR	0	0	TR	TR		TR	1.40	1.44	.010		16.5	3.4	.19	TR		7.5	6.9
005-010	TR	0	0	TR	TR		TR	1.48	1.51	.007		23.7	3.7	.30	TR		7.4	6.8
010-025	TR	0	0	TR	TR		TR	1.47	1.49	.005		9.5	4.0	.08	TR		7.5	6.8
025-050	TR	0	0	TR	TR		TR	1.46	1.50	.009		10.5	4.5	.09	TR		7.8	7.1
050-100	TR	0	0	TR	TR		TR	1.49	1.53	.009		9.9	4.1	.09	8		8.2	7.5
100-150	TR	0	0	TR	TR		TR	1.5 A					5.5		13		8.5	7.8
150-200	TR	0	0	1	TR		1	1.5 A					4.1		12		8.6	8.0

DEPTH	ORGANIC MATTER			IRON	PHOS	EXTRACTABLE BASES 5B4A					ACTY	AL	CAT EXCH		RATIO	RATIO	CA	BASE SAT	
CM	6A1A ORGN CARB PCT	6B1A NITG PCT	C/N	6C2B EXT FE PCT	TOTL PCT	6N2F CA	6O2D MG	6P2B NA	6Q2B K	SUM EXTB	6H1A BACL TEA	6G1E KCL EXT	5A3A EXTB ACTY	5A6A NHAC	8D1 NHAC TO CLAY	8D3 CA TO MG	5F1 SAT NHAC PCT	5C3 EXTB ACTY PCT	5C1 NHAC PCT
						MEQ / 100 G													
000-001	2.15	.130	17				2.2	TR	.5		1.1			9.0	1.50				
001-002	1.59	.092	17				2.1	.0	.4		.8			7.9	1.40				
002-005	1.12	.075	15				1.9	.0	.4		.8			7.1	1.00				
005-010	.68	.061	11			4.9	1.5	.0	.4	6.8	.6		7.4	6.3	.75	3.3	78	92	108
010-025	.52	.052	10			5.3	1.6	.0	.3	7.2	.7		7.9	7.0	.82	3.3	76	91	103
025-050	.42	.038	11				2.1	.0	.4		.6			7.4	.59				
050-100	.24	.026	9				3.2	.0	.2					5.1	.46				
100-150	.27	.026	10				5.1	.0	.1					5.8	.39				
150-200	.15	.016	9				6.3	.1	.2					4.9	.43				

DEPTH	SATURATED PASTE			NA	NA	SALT	GYP	SATURATION EXTRACT 8A1										ATTERBERG	
CM	8E1 REST OHM- CM	8C1B PH	8A H2O PCT	5D2 ESP PCT	5E SAR	8D5 TOTL SOLU PPM	6F1A PCT	8A1A EC MMHOS/ CM	6N1B CA	6O1B MG	6P1B NA	6Q1B K	6I1A CO3	6J1A HCO3	6K1C CL	6L1C SO4	6M1C NO3	4F1 LQID LMIT PCT	4F2 [illegible] INDX
									MEQ / LITER										
000-001		7.0	41.9			330		1.04	7.2	3.7	.1	1.3	.0	8.8	.7	.6	.0		
001-002								.20B											
002-005								.20B											
005-010								.10B											
010-025								.10B											
025-050								.10B											
050-100	6800	8.1						.20B											NP
100-150	6100	8.3						.20B											
150-200								.20B											

(B) 1:2 SOIL WATER RATIO
(A) ESTIMATE

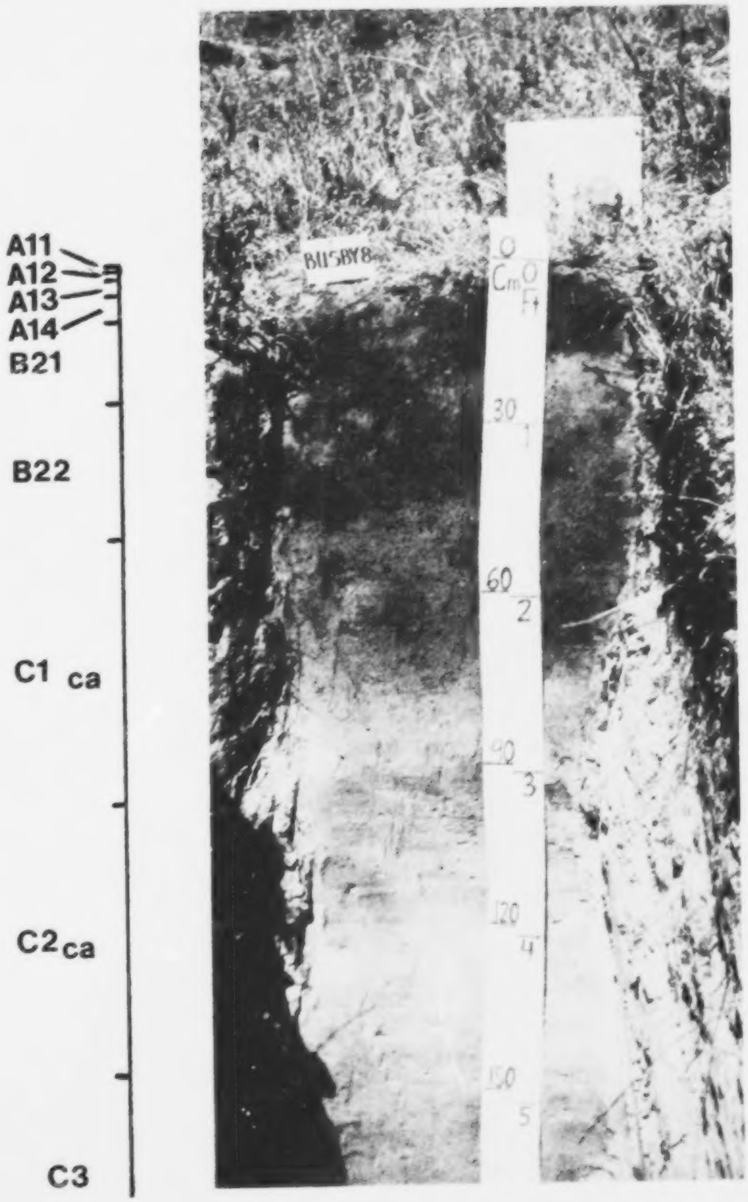
A11
A12
A13
A14
B21
B22
C1 ca
C2 ca
C3
BUSBY8
0
Cm
0
Ft
30
1
60
2
90
3
120
4
150
5

Fig. A-8. Photograph of Chinook-8 soil profile.

Table A-17. Pedon description of 1928-9 soil.

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SOIL SERIES:                          1928 SERIES

SURVEY SAMPLE NO.:                   [illegible]  177- 9
LOCATION:          SE 1/4, NW 1/4, SW 1/4, SECT 35, T2N, R41E, 1 MI SE OF COLSTRIP, MT
CLASSIFICATION:

SITE NO.: [illegible]    COUNTY: SEE REMARKS          ELEVATION: 1,017 METERS        MONTH SAMPLED: AUGUST
SLOPE:        %        CLASS:   NEARLY LEVEL        KIND:        PLANE             ASPECT:
AIR TEMPERATURE:       ANNUAL: 46 DEGREES F         SUMMER: 68 DEGREES F           WINTER: 24 DEGREES F
SOIL TEMPERATURE:      ANNUAL:    DEGREES F         SUMMER:    DEGREES F           WINTER:    DEGREES F
WATER TABLE:           DEPTH:     CM.               MONTH:  AUGUST                 KIND:  NO WATER TABLE
PRECIPITATION:         [illegible] CM.              CONTROL SECTION LIMITS --      UPPER: 025 CM  LOWER: 100 CM
PERMEABILITY:          RAPID                        DRAINAGE CLASS:  SOMEWHAT EXCESSIVELY DRAINED
PHYSIOGRAPHY:          ROLLING OR HILLY UPLANDS                                    STONINESS: CLASS 0
VEGETATION:            GRASSES AND FORBS
PARENT MATERIAL:       SLIGHTLY   WEATHERED   UNCONSOLIDATED MINERAL SEDIMENTS
                       CALCAREOUS SANDSTONE   AND CALCAREOUS SILTSTONE

  HORIZON                                PROFILE DESCRIPTION

  A 11             0 -   1 CM.  ( 0 -   0 IN.)
                LIGHT BROWNISH GRAY (2.5Y  6/2) CRUSHED  ;  LOAMY SAND   ;  DARK GRAYISH BROWN
                (2.5Y  4/2) CRUSHED MOIST   ;  MASSIVE  ;  SOFT    ,  VERY FRIABLE     ,
                NONSTICKY    ,  NONPLASTIC   ;  COMMON  FINE   ROOTS   THROUGHOUT HORIZON   ;
                MANY   FINE   VESICULAR   PORES    ;  MILDLY EFFERVESCENT (HCL)   CONTINUOUS   ;
                MILDLY ALKALINE PH- 7.8  ;  ARBITRARY   BOUNDARY   .

  A 12             1 -   2 CM.  ( 0 -   1 IN.)
                LIGHT BROWNISH GRAY (2.5Y  6/2) CRUSHED  ;  LOAMY SAND   ;  WEAK
                MEDIUM & COARSE    PLATY   STRUCTURE   PARTING TO  MODERATE    VERY FINE   PLATY    ;
                SLIGHTLY HARD    ,  FRIABLE  ,  NONSTICKY     ,  NONPLASTIC   ;  COMMON  FINE
                ROOTS   THROUGHOUT HORIZON   ;  MANY     FINE     IRREGULAR   PORES    ,  FINE
                PORES    ,  MODERATELY EFFERVESCENT (HCL)    CONTINUOUS    ;  MODERATELY ALKALINE PH- 8.2
                ARBITRARY   BOUNDARY   .

  A 13             2 -   5 CM.  ( 1 -   2 IN.)
                LIGHT BROWNISH GRAY (2.5Y  6/2) CRUSHED  ;  LOAMY SAND   ;  DARK GRAYISH BROWN
                (2.5Y  4/2) CRUSHED MOIST   ;  WEAK    MEDIUM &  COARSE    PLATY   STRUCTURE
                PARTING TO  MODERATE    VERY FINE   PLATY    ;  SLIGHTLY HARD    ,  VERY FRIABLE     ,
                NONSTICKY    ,  NONPLASTIC   ;  COMMON  FINE   ROOTS   THROUGHOUT HORIZON   ;
                MANY   FINE   IRREGULAR   PORES    ;  MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ;
                MODERATELY ALKALINE PH- 8.2  ;  GRADUAL WAVY    BOUNDARY   .

  AC 1             5 -  12 CM.  ( 2 -   5 IN.)
                LIGHT BROWNISH GRAY (2.5Y  6/2) CRUSHED  ;  LOAMY SAND   ;  DARK GRAYISH BROWN
                (2.5Y  4/2) CRUSHED MOIST   ;  WEAK    VERY COARSE PLATY   STRUCTURE    ;
                SLIGHTLY HARD    ,  VERY FRIABLE     ,  NONSTICKY     ,  NONPLASTIC    ;  COMMON
                FINE    ROOTS   THROUGHOUT HORIZON   ;  MANY     FINE    IRREGULAR    PORES    ;  10
                PERCENT SANDSTONE    FRAGMENTS   >2 CM    ;  MODERATELY EFFERVESCENT (HCL)
                CONTINUOUS    ;  MODERATELY ALKALINE PH- 8.2  ;  ARBITRARY   BOUNDARY   .

  AC 2            12 -  15 CM.  ( 4 -   6 IN.)
                LIGHT GRAY  (2.5Y  7/2) CRUSHED  ;  LOAMY SAND    ;  LIGHT BROWNISH GRAY (2.5Y  6/2)
                CRUSHED MOIST    ;  WEAK     VERY COARSE PLATY    STRUCTURE     ;  SLIGHTLY HARD     ,
                VERY FRIABLE       ,  NONSTICKY      ,  NONPLASTIC    ;  COMMON  FINE     ROOTS
                THROUGHOUT HORIZON    ;  MANY     FINE     IRREGULAR    PORES    ;  10  PERCENT
                SANDSTONE    FRAGMENTS    >2 CM     ;  MODERATELY EFFERVESCENT (HCL)    CONTINUOUS    ;
                MODERATELY ALKALINE PH- 8.2  ;  GRADUAL WAVY     BOUNDARY   .

  C 1             15 -  55 CM.  ( 6 -  20 IN.)
                LIGHT GRAY  (2.5Y  7/2) CRUSHED  ;  LOAMY SAND    ;  LIGHT BROWNISH GRAY (2.5Y  6/2)
                CRUSHED MOIST     ;  LIGHT BROWNISH GRAY (2.5Y  6/2) CRUSHED  ;  DARK GRAYISH BROWN
                (2.5Y  4/2) CRUSHED MOIST    ;  FEW FINE & MEDIUM  PROMINENT   REDDISH YELLOW
                (7.5YR 6/6) CRUSHED MOTTLES  ;  40  PERCENT VERY HARD   LOAMY SAND  LIGHT GRAY
                (2.5Y  7/2) CRUSHED POCKETS OF CONTRASTING MATERIAL(4    -  CM THICK )   ;  MASSIVE  ;
                SLIGHTLY HARD     ,  VERY FRIABLE       ,  NONSTICKY      ,  NONPLASTIC    ;  FEW FINE
                ROOTS    THROUGHOUT HORIZON    ;  MANY     FINE     IRREGULAR    PORES     ;  30  PERCENT
                SANDSTONE    FRAGMENTS    >8 CM     ,  <8  PERCENT SILTSTONE   FRAGMENTS     ;
                MODERATELY EFFERVESCENT (HCL)    CONTINUOUS    ;  MODERATELY ALKALINE PH- 8.2  ;
                CLEAR     WAVY     BOUNDARY    .

  C 2             55 - 100 CM.  ( 22 -  39 IN.)
                LIGHT BROWNISH GRAY (2.5Y  6/2) CRUSHED   ;  LOAMY SAND    ;  DARK GRAYISH BROWN
                (2.5Y  4/2) CRUSHED MOIST     ;  LIGHT GRAY  (2.5Y  7/2) CRUSHED   ;
                LIGHT BROWNISH GRAY (2.5Y  6/2) CRUSHED MOIST     ;  10  PERCENT VERY HARD
                LOAMY SAND  BROWN    (10YR  4/3) CRUSHED POCKETS OF CONTRASTING MATERIAL(
                 -  CM THICK )   ;  MASSIVE   ;  SLIGHTLY HARD     ,  VERY FRIABLE       ,  NONSTICKY      ,
                NONPLASTIC    ;  FEW FINE     ROOTS    THROUGHOUT HORIZON    ;  MANY     FINE
                IRREGULAR    PORES     ;  30  PERCENT SANDSTONE    FRAGMENTS    >8 CM     ;
                MODERATELY EFFERVESCENT (HCL)    CONTINUOUS    ;  MODERATELY ALKALINE PH- 8.2  ;
                ARBITRARY    BOUNDARY    .

  C 3            100 - 200 CM.  ( 39 -  79 IN.)
                LIGHT BROWNISH GRAY (2.5Y  6/2) CRUSHED   ;  LOAMY SAND    ;  DARK GRAYISH BROWN
                (2.5Y  4/2) CRUSHED MOIST     ;  MASSIVE   ;  SLIGHTLY HARD      ,  VERY FRIABLE       ,
                NONSTICKY      ,  NONPLASTIC    ;  FEW FINE     ROOTS    THROUGHOUT HORIZON    ;  MANY
                FINE     IRREGULAR    PORES     ;  30  PERCENT SANDSTONE    FRAGMENTS    >8 CM     ;
                MODERATELY EFFERVESCENT (HCL)    CONTINUOUS    ;  MODERATELY ALKALINE PH- 8.2  ;
                NOT REACHED BOUNDARY    .

  REMARKS       STRIP-MINE SPOILS NEAR COLSTRIP, MONTANA LEVELED IN 1928.  AUG 9, 1976  SOIL TEM
                P [illegible] C AT 50 CM.  10 LARGE SANDSTONE FRAGMENTS THROUGHOUT THE PROFILE UP TO [illegible]
                 CM.  INTERMITTENT CONVEX-UPWARDS BANDS OF A1 MATERIAL 50 CM WIDE AT 15 CM HIGH
                OCCUR AS DEPOSITIONAL FEATURES.  PROMINENT DIAGONAL SHEAR PLANES PARALLEL TO TH
                E OUTSIDE EDGE OF THE SPOIL PLATFORM MAY REPRESENT THE FORMER EXTENT OF THE PLAT
                FORM DURING DEPOSITION.  PLATY STRUCTURE IN SURFACE 25 CM MAY BE DUE TO COMPACTI
                ON BY HORSES HAULING SPOIL MATERIAL.
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Table A-18. Laboratory analyses of 1928-9 soil.

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SOIL CLASSIFICATION-                                               U. S. DEPARTMENT OF AGRICULTURE
                                                                   SOIL CONSERVATION SERVICE, MTSC
SERIES - - - - - - -SERIES NOT DESIGNATED                          NATIONAL SOIL SURVEY LABORATORY
                                                                   LINCOLN, NEBRASKA
SOIL NO - - - - - - S76MT-087-9    COUNTY - - -  ROSEBUD

GENERAL METHODS- - -1A, 1B1B, 2A1, 2B            SAMPLE NOS. 76P0606-76P0615

-----------------------------------------------------------------------------------------------------------------------
DEPTH     HORIZON (- - - - - - - - - - - PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B - - - - - - - - - - - - )RATIO
                                    FINE  (- - - - - - SAND - - - - - -)(- - -SILT- - - -)FAML  INTR  FINE  NON-  8D1
                  SAND  SILT  CLAY  CLAY  VCOS  CORS  MEDS  FNES  VFNS  COSI  FNSI  VFSI  TEXT  II    CLAY  CO3-  15-
                  2-    .05-  LT    LT    2-    1-    .5-   .25-  .10-  .05   .02   .005- SAND  .2-   TO    CLAY  BAR
                  .05   .002  .002  .0002 1     .5    .25   .10   .05   .02   .002  .002  2-.1  .02   CLAY        TO
 CM               (- - - - - - - - - - - - - - - - - PCT LT 2MM - - - - - - - - - - - - - - - - - - -)PCT   PCT   CLAY
-----------------------------------------------------------------------------------------------------------------------
000-001   A11     78.7  12.4  8.9         .2    .6    5.4   57.2  15.3  8.2   4.2         63.4                    .42
001-002   A12     78.8  11.5  9.7         .1    .4    5.0   57.5  15.8  8.0   3.5         63.0                    .36
002-005   A13     78.5  12.6  8.9         .2    .3    5.6   58.1  14.3  7.8   4.8         64.2                    .38
005-010   AC1     77.3  13.0  9.7         .2    .6    5.9   54.8  15.8  7.7   5.3         61.5                    .34
010-015   AC2     80.5  11.8  7.7         TR    .3    5.1   60.7  14.4  7.6   4.2         66.1                    .39
015-050   C1      81.0  11.7  7.3         .2    .4    6.0   61.6  12.8  7.0   4.7         68.2                    .42
050-100   C2      84.8  6.7   8.5         TR    .4    6.7   65.5  12.2  6.4   .3          72.6                    .38
100-200   C3      83.3  9.0   7.7         .2    .4    10.9  60.3  11.5  5.7   3.3         71.8                    .36
100-200   C3 (A)
000-005      (B)

-----------------------------------------------------------------------------------------------------------------------
DEPTH  (PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2)(  BULK DENSITY  )(- - - -WATER  CONTENT- - - -) CARBONATE  (- -PH - -)
        VOL.  (- - - - - - - WEIGHT - - - - - - -)4A1D  4A1H  4D1   4B1C  4B1C  4B2   4C1         6F1B  3A1A  8C1A  8C1E
        GT    GT    75-20 20-5  5-2   LT    20-2  1/3-  OVEN  COLE  1/10  1/3-  15-   WRD         LT    LT    1/1   1/2
        2     75                      .074  PCT   BAR   DRY         BAR   BAR   BAR   CM/         2     .002  H2O   CACL
 CM     PCT   PCT   (- - - PCT LT 75 - - -) LT20  G/CC  G/CC        PCT   PCT   PCT   CM          PCT   PCT
-----------------------------------------------------------------------------------------------------------------------
000-001 1     0     0     TR    1           1     1.5 C                         3.7
001-002 1     0     0     TR    1           1     1.5 C                         3.5
002-005 1     0     TR    1     TR          1     1.5 C                         3.4
005-010 1     0     TR    1     TR          1     1.51  1.54  .007        12.5  3.3   .14
010-015 1     0     TR    1     1           2     1.62  1.66  .008        9.8   3.0   .11
015-050 34    0     18    27    1           34    1.6 C                         3.1
050-100 5     0     11    TR    TR          TR    1.6 C                         3.2               6           8.6   7.9
100-200 13    0     18    1     TR          1     1.65  1.71  .012        13.3  2.8   .17         9           8.5   7.8
100-200 TR    0     3     TR    TR          TR    1.69  1.71  .004        7.6   2.6   .09         9           8.5   7.7
000-005                                           1.49  1.53  .009        10.4

-----------------------------------------------------------------------------------------------------------------------
DEPTH  (ORGANIC MATTER  ) IRON  PHOS  (- -EXTRACTABLE BASES 5B4A- -)ACTY  AL    (CAT EXCH)  RATIO RATIO CA    (BASE SAT)
        6A1A  6B1A  C/N   6C2B        6N2E  6O2D  6P2B  6Q2B        6H1A  6G1E  5A3A  5A6A  8D1   8D3   5F1   5C3   5C1
        ORGN  NITG        EXT   TOTL  CA    MG    NA    K     SUM   BACL  KCL   EXTS  NHAC  NHAC  CA    SAT   EXTB  NHAC
        CARB              FE                                  EXTB  TEA   EXT   ACTY        TO    TO    NHAC  ACTY
 CM     PCT   PCT         PCT   PCT   (- - - - - - - - - - - -MEQ / 100  G- - - - - - - - ) CLAY  MG    PCT   PCT   PCT
-----------------------------------------------------------------------------------------------------------------------
000-001 1.08  .062  17
001-002 .65   .042  15
002-005 .56   .036  16
005-010 .38   .028  14
010-015 .25   .019  13
015-050 .13   .009  14
050-100 .13   .012  11                      4.0   .0    .1                          3.3   .45
100-200 .08   .007  11                      3.5   .0    .1                          3.6   .42
100-200                                     3.4   .0    .1                          3.5   .45
000-005

-----------------------------------------------------------------------------------------------------------------------
DEPTH  (SATURATED PASTE)  NA    NA    SALT  GYP   (- - - - - - - - SATURATION EXTRACT 8A1- - - - - - - - - - )ATTERBERG
        8E1   8C1B  8A    5D2   5E    8D5   6F1A  8A1A  6N1B  6O1B  6P1B  6Q1B  6I1A  6J1A  6K1C  6L1C  6M1C  4F1   4F2
        REST  PH    H2O   ESP   SAR   TOTL        EC    CA    MG    NA    K     CO3   HCO3  CL    SO4   NO3   LOID  PLST
        OHM-                          SOLU        MMHOS/                                                      LMIT  INDX
 CM     CM          PCT   PCT         PPM   PCT   CM    (- - - - - - - - - - MEQ / LITER - - - - - - - - - -) PCT
-----------------------------------------------------------------------------------------------------------------------
000-001       7.4   30.6              270         1.18  10.0  2.6   .1    1.3   .0    10.1  1.1   .9    .0
001-002       7.8   28.9              100         .55   4.2   .9    .0    .5    .0    4.2   .4    .4    .2
002-005       7.8   28.9              90          .47   3.6   .9    .0    .4    .0    3.7   .2    .3    .0
005-010                                           .200
010-015                                           .200
015-050                                           .200
050-100 8200  8.3                                 .200                                                              NP
100-200 8700  8.3                                 .200
100-200
000-005
-----------------------------------------------------------------------------------------------------------------------
(A)  SANDSTONE FRAGMENTS.
(B)  CLOD OF A11, A12, AND A13 FOR BULK DENSITY AND MOISTURE RETENTION.
(C)  ESTIMATE
(D)  1:2 SOIL WATER RATIO.
```

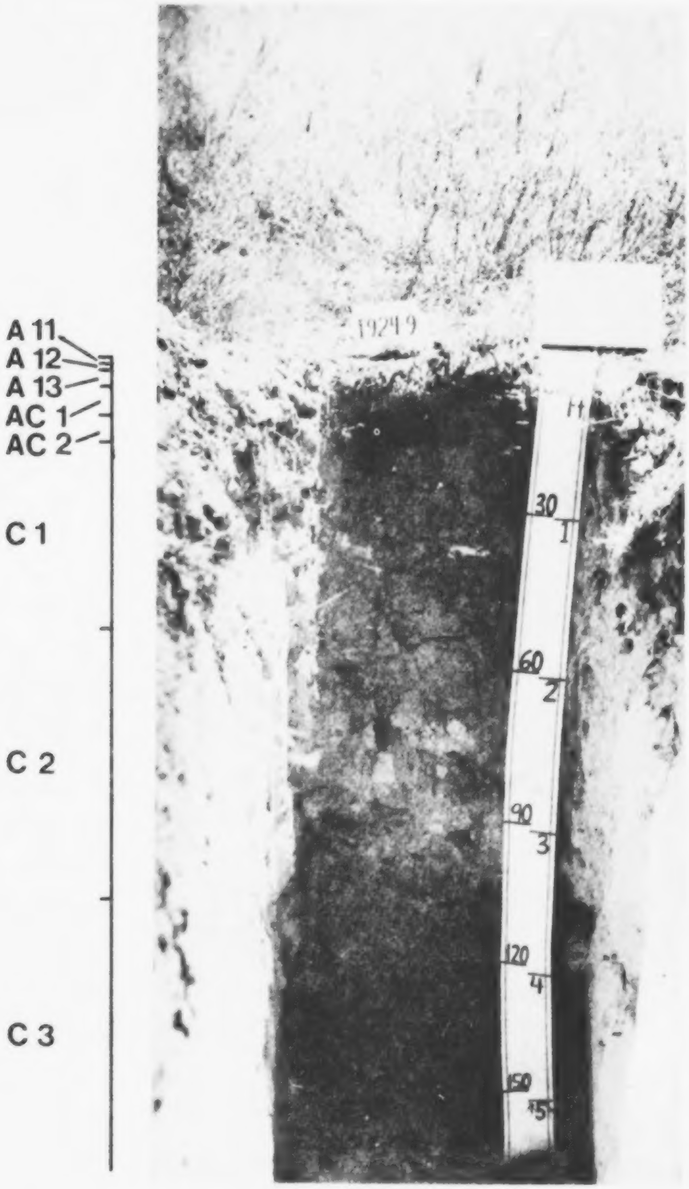
A 11
A 12
A 13
AC 1
AC 2
C 1
C 2
C 3
30
1
60
2
90
3
120
4
150
5

Fig. A-9. Photograph of 1928-9 soil profile.

Table A-19. Pedon description of 1929-10 soil.

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SOIL SERIES:                          1932 SPOILS

SURVEY SAMPLE NO.:                    C     [illegible] 10
LOCATION:          NE 1/4, NW 1/4, NW 1/4, SEC 1 T1N, R41E, 2 MI ESE OF COLSTRIP, MT.
CLASSIFICATION:

SITE NO.: [illegible]  COUNTY: SEE REMARKS       ELEVATION: [illegible] METERS     MONTH SAMPLED: AUGUST
SLOPE:   [illegible]   CLASS:  NEARLY LEVEL      KIND:        PLANE                ASPECT:
AIR TEMPERATURE:    ANNUAL: 46 DEGREES F         SUMMER: 68 DEGREES F              WINTER: 24 DEGREES F
SOIL TEMPERATURE:   ANNUAL:    DEGREES F         SUMMER:    DEGREES F              WINTER:    DEGREES F
WATER TABLE:        DEPTH:     CM.               MONTH:  AUGUST                    KIND:  NO WATER TABLE
PRECIPITATION:      [illegible] CM.              CONTROL SECTION LIMITS --         UPPER: [illegible] CM  LOWER: [illegible] CM
PERMEABILITY:       MODERATELY RAPID             DRAINAGE CLASS: WELL DRAINED
PHYSIOGRAPHY:       LEVEL OR UNDULATING UPLANDS                                    STONINESS: CLASS 0
MICRORELIEF:        ON CREST AND SLOPE
VEGETATION:         GRASSES AND FORBS AND SHRUBS
PARENT MATERIAL:    SLIGHTLY   WEATHERED   UNCONSOLIDATED MINERAL SEDIMENTS
                    CALCAREOUS SANDSTONE    AND INTERBEDDED SHALE AND SILTSTONE

  HORIZON                              PROFILE DESCRIPTION

  A 11        [illegible] - 1 CM. ( 0 - [illegible] IN.)
              PALE BROWN (10YR 6/3) CRUSHED ; LOAM    ; YELLOWISH BROWN (10YR 5/4) CRUSHED
              MOIST  ; MODERATE   FINE   PLATY  STRUCTURE  ; SOFT   , VERY FRIABLE   ,
              NONSTICKY  , SLIGHTLY PLASTIC  ; MANY  FINE  ROOTS  THROUGHOUT HORIZON  ;
              MANY  FINE  TUBULAR CONTINUOUS PORES  , COMMON TO MANY FINE  VESICULAR
              PORES  ; FEW SANDSTONE  FRAGMENTS  >2 MM  , COMMON SILTSTONE  FRAGMENTS
              >2 CM  ; MILDLY EFFERVESCENT (HCL)  CONTINUOUS  ; MODERATELY ALKALINE PH= 8.4
              (BROMTHYMOL BLUE)  ; ARBITRARY  BOUNDARY  .

  A 12        1 - 2 CM. ( 0 - 1 IN.)
              PALE BROWN (10YR 6/3) CRUSHED ; SANDY LOAM  ; YELLOWISH BROWN (10YR 5/4)
              CRUSHED MOIST  ; MODERATE  FINE  PLATY  STRUCTURE  ; SOFT  ,
              VERY FRIABLE  , NONSTICKY  , NONPLASTIC  ; MANY  FINE  ROOTS
              THROUGHOUT HORIZON  ; MANY  FINE  TUBULAR CONTINUOUS PORES  ,
              COMMON TO MANY FINE  VESICULAR  PORES  ; FEW SANDSTONE  FRAGMENTS  >2 MM  ,
              COMMON  SILTSTONE  FRAGMENTS  >2 CM  ; MODERATELY EFFERVESCENT (HCL)
              CONTINUOUS  ; MODERATELY ALKALINE PH= 8.4 (BROMTHYMOL BLUE)  ; ARBITRARY
              BOUNDARY  .

  A 13        2 - 5 CM. ( 1 - 2 IN.)
              LT. YELLOWISH BROWN (2.5Y 6/4) CRUSHED ; VERY FINE SANDY LOAM  ;
              LIGHT OLIVE BROWN  (2.5Y 5/4) CRUSHED MOIST  ; MODERATE  FINE  PLATY
              STRUCTURE  ; SLIGHTLY HARD  , VERY FRIABLE  , NONSTICKY  ,
              SLIGHTLY PLASTIC  ; MANY  FINE  ROOTS  THROUGHOUT HORIZON  ; MANY
              FINE  TUBULAR CONTINUOUS PORES  , COMMON TO MANY FINE  VESICULAR  PORES  ;
              FEW SANDSTONE  FRAGMENTS  >2 MM  , COMMON SILTSTONE  FRAGMENTS  >2 CM  ;
              MODERATELY EFFERVESCENT (HCL)  CONTINUOUS  ; STRONGLY ALKALINE  PH= 8.8
              (BROMTHYMOL BLUE)  ; ARBITRARY  BOUNDARY  .

  C 1         5 - 10 CM. ( 2 - 4 IN.)
              LIGHT BROWNISH GRAY (2.5Y 6/2) CRUSHED  ; VERY FINE SANDY LOAM  ;
              LIGHT OLIVE BROWN  (2.5Y 5/4) CRUSHED MOIST  ; MODERATE  FINE  PLATY
              STRUCTURE  ; SLIGHTLY HARD  , VERY FRIABLE  , NONSTICKY  , NONPLASTIC  ;
              MANY  FINE  ROOTS  THROUGHOUT HORIZON  ; MANY  FINE  TUBULAR CONTINUOUS
              PORES  , MANY  FINE  VESICULAR  PORES  ; FEW SANDSTONE  FRAGMENTS
              >2 MM  , COMMON  SILTSTONE  FRAGMENTS  >2 CM  ; MODERATELY EFFERVESCENT
              (HCL)  CONTINUOUS  ; STRONGLY ALKALINE  PH= 8.8 (BROMTHYMOL BLUE)  ; CLEAR
              WAVY  BOUNDARY  .

  C 2         10 - 50 CM. ( 4 - 20 IN.)
              LIGHT GRAY (2.5Y 7/2) CRUSHED  ; LOAM  ; LIGHT OLIVE BROWN  (2.5Y 5/4)
              CRUSHED MOIST  ; MODERATE  MEDIUM PLATY  STRUCTURE  ; HARD  , FRIABLE  ,
              NONSTICKY  , SLIGHTLY PLASTIC  ; MANY  FINE  ROOTS  THROUGHOUT HORIZON  ;
              MANY  FINE  TUBULAR CONTINUOUS PORES  ; COMMON MIXED SEDIMENTARY
              FRAGMENTS  >2 MM  , FEW SILTSTONE  FRAGMENTS  >2 CM  ;
              MODERATELY EFFERVESCENT (HCL)  CONTINUOUS  ; STRONGLY ALKALINE  PH= 8.8
              (BROMTHYMOL BLUE)  ; ARBITRARY  BOUNDARY  .

  C 3         50 - 100 CM. ( 20 - 39 IN.)
              LIGHT GRAY (2.5Y 7/2) CRUSHED  ; LOAM  ; LIGHT OLIVE BROWN  (2.5Y 5/4)
              CRUSHED MOIST  ; MASSIVE  ; HARD  , FRIABLE  , NONSTICKY  ,
              SLIGHTLY PLASTIC  ; COMMON  FINE  ROOTS  THROUGHOUT HORIZON  ; MANY
              FINE  TUBULAR CONTINUOUS PORES  ; COMMON MIXED SEDIMENTARY  FRAGMENTS
              >2 MM  , FEW SILTSTONE  FRAGMENTS  >2 CM  ; MODERATELY EFFERVESCENT (HCL)
              CONTINUOUS  ; STRONGLY ALKALINE  PH= 9.0 (BROMTHYMOL BLUE)  ; ARBITRARY
              BOUNDARY  .

  C 4         100 - 200 CM. ( 39 - 79 IN.)
              LIGHT GRAY (2.5Y 7/2) CRUSHED  ; CLAY LOAM  ; LIGHT OLIVE BROWN  (2.5Y 5/4)
              CRUSHED MOIST  ; MASSIVE  ; HARD  , FIRM  , STICKY  ,
              SLIGHTLY PLASTIC  ; FEW FINE  ROOTS  THROUGHOUT HORIZON  ; MANY  FINE
              TUBULAR CONTINUOUS PORES  ; FEW SANDSTONE  FRAGMENTS  >2 MM  , COMMON
              SILTSTONE  FRAGMENTS  >2 CM  ; MODERATELY EFFERVESCENT (HCL)  CONTINUOUS  ;
              STRONGLY ALKALINE  PH= 8.8 (BROMTHYMOL BLUE)  ; NOT REACHED BOUNDARY  .

  REMARKS:    STRIP-MINE SPOILS NEAR COLSTRIP, MONTANA LEVELED IN 1932.  AUG 11, 1976 SOIL TEM
              P [illegible] C AT 50 CM.  UPPER HALF OF C2 HAS MODERATE MEDIUM PLATY STRUCTURE.  THYM
              OL BLUE INDICATOR GIVES PH VALUES 0.[illegible] TO 1.0 HIGHER THAN METER.
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Table A-20. Laboratory analyses of 1929-10 soil.

SOIL CLASSIFICATION-
SERIES - - - - - - - -MINE SPOIL
SOIL NO - - - - - - - S76MT-087-10   COUNTY - - - ROSEBUD
GENERAL METHODS- - -1A, 1B1B, 2A1, 2B   SAMPLE NOS. 76P0616-76P0624

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, MTSC
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA

DEPTH CM	HORIZON	PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B: SAND 2-.05 PCT LT 2MM	SILT .05-.002	CLAY LT .002	FINE CLAY LT .0002	SAND: VCOS 2-1	CORS 1-.5	MEDS .5-.25	FNES .25-.10	VFNS .10-.05	SILT: COSI .05-.02	FNSI .02-.002	VFSI .005-.002	FAML TEXT SAND 2-.1	INTR II .2-.02	FINE CLAY TO CLAY PCT	NON-CO3-CLAY PCT	RATIO 8D1 15-BAR TO CLAY
000-001	A11	42.0	46.2	11.8		.4	.5	1.7	26.5	12.9	25.3	20.9		29.1			12	.98
001-002	A12	50.7	38.5	10.8		.5	.4	1.4	30.5	17.9	22.3	16.2		32.8			11	.59
002-005	A13	46.0	40.5	13.5		.5	.6	1.2	25.7	18.0	20.2	20.3		28.0			14	.33
005-010	C1	58.1	29.8	12.1		.3	.5	1.4	35.7	20.2	16.8	13.0		37.9			12	.41
010-050	C2	49.1	33.1	17.8		.2	.5	1.3	32.8	14.3	12.3	20.8		34.8			18	.33
050-100	C3	61.0	26.9	12.1		.1	.4	3.1	43.9	13.5	8.7	18.2		47.5			11	.55
100-200	C4	63.2	25.1	11.7		.3	.4	2.7	46.0	13.8	7.3	17.8		49.4			12	.48
--------	SHALE																	
000-005	(A)																	

DEPTH CM	PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2: VOL. GT 2 PCT	WEIGHT: GT 75 PCT	75-20 PCT LT 75	20-5	5-2	LT .074	20-2 PCT LT20	BULK DENSITY: 4A1D 1/3-BAR G/CC	4A1H OVEN DRY G/CC	4D1 COLE	WATER CONTENT: 4B1C 1/10 BAR PCT	4B1C 1/3-BAR PCT	4B2 15-BAR PCT	4C1 WRD CM/CM	CARBONATE: 6E1B LT 2 PCT	3A1A LT .002 PCT	PH: 8C1A 1/1 H2O	8C1E 1/2 CACL
000-001	2	0	0	2	2		4	1.1 B					11.6		TR		7.7	7.1
001-002	2	0	0	2	1		3	1.2 B					6.4		16		7.7	7.3
002-005	2	0	0	2	1		3	1.2 B					4.4		16		7.9	7.4
005-010	2	0	0	2	2		4	1.5	1.58	.008		11.1	5.0	.09	15		8.1	7.5
010-050	TR	0	0	1	TR		1	1.5 B					5.9		15		8.3	7.8
050-100	13	0	0	16	5		21	1.53	1.57	.008		18.5	6.6	.16	14	1	8.6	7.9
100-200	TR	0	0	TR	TR		TR	1.5 B					10.3		20	2	8.5	7.8
--------															3		8.5	7.9
000-005								1.23	1.31	.021		17.2						

DEPTH CM	ORGANIC MATTER: 6A1A ORGN CARB PCT	6B1A NITG PCT	C/N	IRON 6C2B EXT FE PCT	PHOS TOTL PCT	EXTRACTABLE BASES 5B4A: 6N2E CA MEQ / 100 G	6O2D MG	6P2B NA	6Q2B K	SUM EXTB	ACTY 6H1A BACL TEA	AL 6G1F KCL EXT	CAT EXCH 5A3A EXTB ACTY	5A6A NHAC	RATIO 8D1 NHAC TO CLAY	RATIO 8D3 CA TO MG	CA 5F1 SAT NHAC PCT	BASE SAT 5C3 EXTB ACTY PCT	5C1 NHAC PCT
000-001	4.63	.379	12				4.2	TR	1.3		1.4			17.0	1.44				
001-002	1.84	.188	10				4.0	TR	.5					5.9	.55				
002-005	1.09	.079	14				4.2	TR	.4					4.6	.34				
005-010	.73	.045	16				3.8	TR	.3					4.2	.35				
010-050	.29	.026	11				5.6	TR	.3					5.0	.28				
050-100	.19	.030	6				6.4	.0	.1					3.8	.31				
100-200	.21	.024	9				9.5	.1	.2					5.6	.46				
--------	.19	.026	7				9.5	.1	.3					6.4					
000-005																			

DEPTH CM	SATURATED PASTE: 8E1 REST OHM-CM	8C1B PH	8A H2O PCT	NA 5D2 ESP PCT	NA 5E SAR	SALT 8D5 TOTL SOLU PPM	GYP 6F1A PCT	SATURATION EXTRACT 8A1: 8A1A EC MMHOS/CM	6N1B CA MEQ / LITER	6O1B MG	6P1B NA	6Q1B K	6I1A CO3	6J1A HCO3	6K1C CL	6L1C SO4	6M1C NO3	ATTERBERG 4F1 LQID LMIT PCT	4F2 PLST INDX
000-001		6.7	101.0			2400	0	2.86	20.8	9.4	.1	7.0	.0	25.7	2.2	1.6	.0		
001-002		7.1	43.7			580		1.73	13.3	5.2	.1	2.2	.0	16.3	1.6	.7	.0		
002-005		7.1	32.7			340		1.39	10.7	4.0	.1	1.6	.0	11.7	1.2	.7	.0		
005-010		7.4	28.1			170		.87	6.1	2.2	.1	1.3	.0	5.4	.7	.5	.0		
010-050		7.8	35.6			100		.43	2.3	1.5	.1	.4	.0	2.5	.3	.3	.0		
050-100	6200	8.2						.20C											
100-200	4400	8.3						.20C											
--------								.20C											
000-005																			

(A) CLOD OF A11, A12, AND A13 FOR BULK DENSITY AND MOISTURE RETENTION.
(B) ESTIMATE
(C) 1:2 SOIL WATER RATIO.

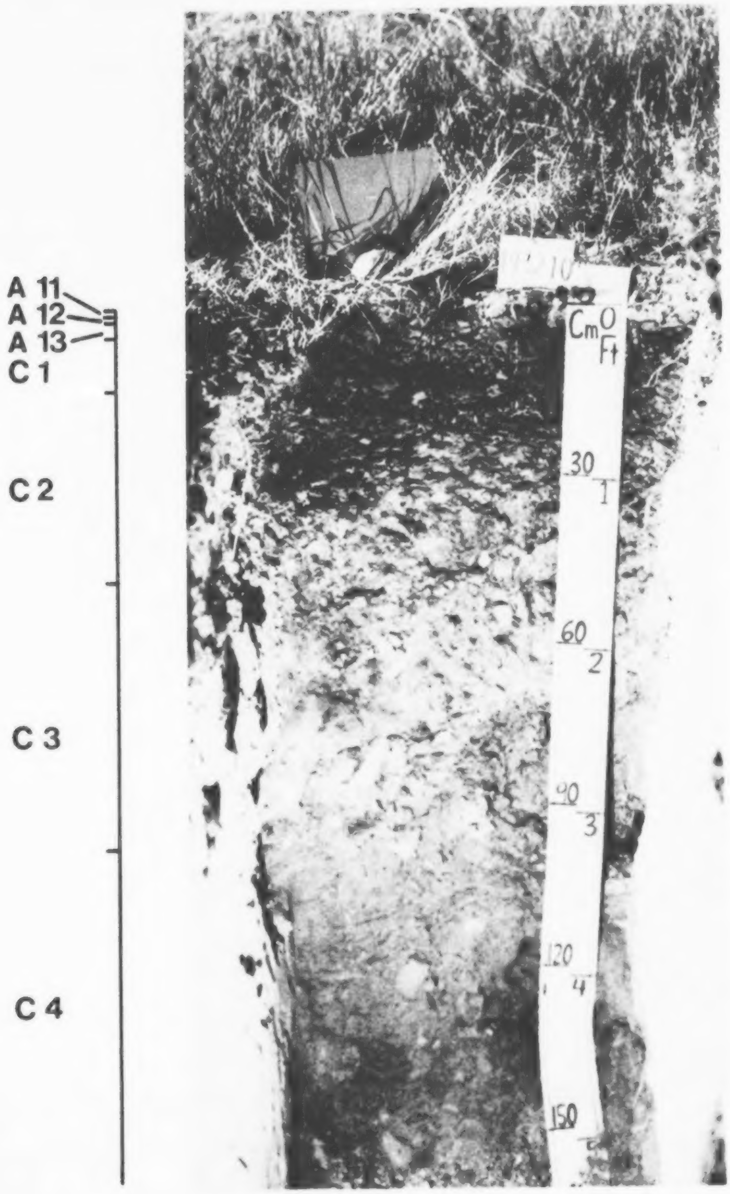
A 11
A 12
A 13
C 1
C 2
C 3
C 4
Cm
Ft
0
30
1
60
2
90
3
120
4
150

Fig. A-10. Photograph of 1929-10 soil profile.

Table A-21. Pedon description of 1975-11 soil.

```
SOIL SERIES:                              1975 SPOILS

SURVEY SAMPLE NO.:                        [illegible]   11
LOCATION:          SE 1/4, SW 1/4, NW 1/4, SECT 18 T1N, R41E, 4 MI SE OF COLSTRIP, MT
CLASSIFICATION:

SITE NO.:  [illegible] 11   OTHERS: SEE REMARKS        ELEVATION: [illegible] METERS      MONTH SAMPLED: AUGUST
SLOPE:          [illegible]  CLASS:  NEARLY LEVEL       KIND:        PLANE                 ASPECT:
AIR TEMPERATURE:     ANNUAL: [illegible] DEGREES F      SUMMER: [illegible] DEGREES F      WINTER: 24 DEGREES F
SOIL TEMPERATURE:    ANNUAL:    DEGREES F               SUMMER:    DEGREES F               WINTER:    DEGREES F
WATER TABLE:          DEPTH:     CM.                    MONTH:  AUGUST                     KIND:  NO WATER TABLE
PRECIPITATION:        [illegible] CM.                   CONTROL SECTION LIMITS --          UPPER: 025 CM  LOWER: 100 CM
PERMEABILITY:        MODERATELY SLOW                    DRAINAGE CLASS:  MODERATELY WELL DRAINED
PHYSIOGRAPHY:        LEVEL TO UNDULATING UPLANDS                                           STONINESS: CLASS 1
MICRORELIEF:         [illegible] SLOPE AND DEPRESSION
VEGETATION:          GRASSES AND FORBS
PARENT MATERIAL:     SLIGHTLY   WEATHERED   UNCONSOLIDATED MINERAL SEDIMENTS
                     CONSISTS OF SANDSTONE    AND INTERBEDDED SHALE AND SILTSTONE

  HORIZON                               PROFILE DESCRIPTION

  A 11           [illegible] CM. ( [illegible] - [illegible] IN.)
                 PALE BROWN (10YR 6/3) CRUSHED ; SANDY LOAM  ; WEAK   FINE   PLATY
                 STRUCTURE   ; SOFT    , VERY FRIABLE    , NONSTICKY   , SLIGHTLY PLASTIC    ;
                 FEW FINE   ROOTS  THROUGHOUT HORIZON  ; MANY   FINE   VESICULAR   PORES   ;
                 FEW SANDSTONE   FRAGMENTS   >2 CM   ; MODERATELY EFFERVESCENT (HCL)  CONTINUOUS  ;
                 MODERATELY ALKALINE PH= [illegible] (PH METER)  ; ARBITRARY   BOUNDARY  .

  A 12           [illegible] CM. ( [illegible] - 1 IN.)
                 PALE BROWN  (10YR  6/3) CRUSHED  ; SANDY LOAM  ; DK. YELLOWISH BROWN (10YR  4/4)
                 CRUSHED MOIST   ; WEAK    FINE    PLATY   STRUCTURE    ; SOFT    ,
                 VERY FRIABLE    , NONSTICKY    , SLIGHTLY PLASTIC     ; FEW FINE    ROOTS
                 THROUGHOUT HORIZON  ; FEW TO COMMON   FINE    VESICULAR   PORES   ; FEW
                 SANDSTONE   FRAGMENTS   >2 CM   ; MODERATELY EFFERVESCENT (HCL)  CONTINUOUS  ;
                 STRONGLY ALKALINE   PH= [illegible] (PH METER)  ; ARBITRARY   BOUNDARY  .

  A 13           [illegible] CM. ( 1 - 2 IN.)
                 PALE BROWN  (10YR  6/3) CRUSHED  ; SANDY LOAM   ; DK. YELLOWISH BROWN (10YR  4/4)
                 CRUSHED MOIST    ; WEAK    COARSE  PLATY   STRUCTURE    ; SOFT    ,
                 VERY FRIABLE    , NONSTICKY    , SLIGHTLY PLASTIC     ; FEW FINE    ROOTS
                 THROUGHOUT HORIZON   ; FEW TO COMMON   FINE    VESICULAR   PORES   ; FEW
                 SANDSTONE   FRAGMENTS   >2 CM   ; MODERATELY EFFERVESCENT (HCL)  CONTINUOUS  ;
                 MODERATELY ALKALINE PH= [illegible] (PH METER)  ; ARBITRARY   BOUNDARY  .

  [illegible]    [illegible] CM. ( 2 - [illegible] IN.)
                 PALE BROWN  (10YR  6/3) CRUSHED  ; SANDY LOAM  ; YELLOWISH BROWN (10YR  5/4)
                 CRUSHED MOIST    ; WEAK    COARSE  PLATY   STRUCTURE    ; SLIGHTLY HARD    ,
                 FRIABLE  , NONSTICKY    , SLIGHTLY PLASTIC     ; FEW FINE    ROOTS
                 THROUGHOUT HORIZON   ; FEW FINE    TUBULAR CONTINUOUS  PORES    , COMMON  FINE
                 VESICULAR   PORES    ; FEW SANDSTONE   FRAGMENTS   >2 CM    ;
                 MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ; MODERATELY ALKALINE PH= [illegible]
                 (PH METER)   ; ARBITRARY    BOUNDARY   .

  [illegible]    [illegible] CM. ( [illegible] - 11 IN.)
                 PALE BROWN  (10YR  6/3) CRUSHED  ; SANDY LOAM   ; YELLOWISH BROWN (10YR  5/4)
                 CRUSHED MOIST    ; MASSIVE  ; SLIGHTLY HARD    , FRIABLE  , NONSTICKY    ,
                 SLIGHTLY PLASTIC     ; FEW FINE    ROOTS  THROUGHOUT HORIZON   ; FEW FINE
                 TUBULAR CONTINUOUS  PORES    ; MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ;
                 STRONGLY ALKALINE   PH= [illegible] (PH METER)   ; ABRUPT  WAVY    BOUNDARY   .

  C  1           [illegible] CM. ( 11 - [illegible] IN.)
                 LIGHT GRAY  (5Y7/1) CRUSHED  ; LOAM     ; LIGHT GRAY  (5Y6/1) CRUSHED MOIST    ;
                 MASSIVE  ; SLIGHTLY HARD    , FRIABLE  , NONSTICKY    , SLIGHTLY PLASTIC     ;
                 MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ; STRONGLY ALKALINE   PH= [illegible]
                 (PH METER)   ; ARBITRARY   BOUNDARY   .

  C  2           [illegible] CM. ( [illegible] - [illegible] IN.)
                 LIGHT GRAY  (2.5Y  7/2) CRUSHED  , LOAM     ; LIGHT BROWNISH GRAY (2.5Y  6/2)
                 CRUSHED MOIST    ; MASSIVE  ; SOFT     , FRIABLE  , NONSTICKY    ,
                 SLIGHTLY PLASTIC     ; FEW SANDSTONE   FRAGMENTS   >2 CM    ;
                 MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ; STRONGLY ALKALINE   PH= [illegible]
                 (PH METER)   ; ABRUPT  WAVY    BOUNDARY   .

  C  3           [illegible] CM. ( [illegible] - [illegible] IN.)
                 LIGHT GRAY  (5Y7/1) CRUSHED     ; LOAM     ; LIGHT GRAY  (5Y6/1) CRUSHED
                 MOIST    , MASSIVE  ; SLIGHTLY HARD    , FRIABLE  , NONSTICKY    ,
                 SLIGHTLY PLASTIC     ; FEW SANDSTONE   FRAGMENTS   >2 CM    ;
                 MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ; STRONGLY ALKALINE   PH= [illegible]
                 (PH METER)   ; ABRUPT  WAVY    BOUNDARY   .

  C  4           [illegible] CM. ( [illegible] - [illegible] IN.)
                 LIGHT GRAY  (2.5Y  7/2) CRUSHED  ; SANDY LOAM   ; LIGHT BROWNISH GRAY (2.5Y  6/2)
                 CRUSHED MOIST    ; MASSIVE  ; SOFT     , VERY FRIABLE     , NONSTICKY    ,
                 NONPLASTIC    ; MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ; STRONGLY ALKALINE
                 PH= [illegible] (PH METER)   ; NOT REACHED BOUNDARY   .

  REMARKS        [illegible] SPOILS NEAR COLSTRIP, MONTANA [illegible] IN 1975.  AUG 12, 1976  SOIL T
                 [illegible] AT 50 CM.  ROOTS ARE MATTED AT THE TOP OF THE C1.  PROFILE IS MOIST
                 [illegible] CM.  ALL [illegible] HORIZONS ARE [illegible] MATERIAL.
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Table A-22. Laboratory analyses of 1975-11 soil.

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, MTSC
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA

SOIL CLASSIFICATION-

SERIES - - - - - - -SERIES NOT DESIGNATED

SOIL NO - - - - - - S76MT-087-11 COUNTY - - - ROSEBUD

GENERAL METHODS- - -1A, 1B1B, 2A1, 2B SAMPLE NOS. 76P0625-76P0634

DEPTH	HORIZON	PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B																RATIO
					FINE	SAND					SILT							
CM		SAND 2-.05	SILT .05-.002	CLAY LT .002	CLAY LT .0002	VCOS 2-1	CORS 1-.5	MEDS .5-.25	FNES .25-.10	VFNS .10-.05	COSI .05-.02	FNSI .02-.002	VFSI .005-.002	FAML TEXT SAND 2-.1	INTR II .2-.02	FINE CLAY TO CLAY PCT	NON-CO3-CLAY PCT	8D1 15-BAR TO CLAY
		PCT LT 2MM																
000-001	A11	13.1	76.8	10.1		.1	.2	.5	5.0	7.3	67.9	8.9		5.8			9	.37
001-002	A12	75.7	15.0	9.3		.8	.8	2.6	53.3	18.2	7.3	7.7		57.5			8	.40
002-005	A13	74.6	16.9	8.5		.6	.7	2.9	52.1	18.3	5.5	11.4		56.3			8	.48
005-010	A14	75.9	16.4	7.7		.5	.6	2.6	55.2	17.0	7.5	8.9		58.9			7	.55
010-028	A15	75.7	15.4	8.9		.5	.5	2.7	53.8	18.2	8.5	6.9		57.5			8	.45
028-050	C1	73.1	19.2	7.7		.2	.6	3.0	53.5	15.8	8.7	10.5		57.3			8	.56
050-080	C2	68.8	22.7	8.5		.2	.5	3.0	46.1	19.0	10.6	12.1		49.8			9	.45
080-100	C3	61.3	33.1	5.6		.2	.6	1.7	29.9	28.9	19.8	13.3		32.4			6	.61
100-200	C4	74.6	19.7	5.7		.1	.6	2.7	50.1	21.1	7.9	11.8		53.5			6	.70
000-005	(A)																	

DEPTH	PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2							BULK DENSITY			WATER CONTENT				CARBONATE		PH	
	VOL.		WEIGHT															
CM	GT 2 PCT	GT 75 PCT	75-20	20-5	5-2	LT .074	20-2 PCT LT20	4A1D 1/3-BAR G/CC	4A1H OVEN DRY G/CC	4D1 COLE	4B1C 1/10 BAR PCT	4B1C 1/3-BAR PCT	4B2 15-BAR PCT	4C1 WRD CM/CM	6E1B LT 2 PCT	3A1A LT .002 PCT	8C1A 1/1 H2O	8C1E 1/2 CACL
			PCT LT 75															
000-001	9	0	2	10	3		13	1.5 B					3.7		11	1	8.3	7.7
001-002	7	0	2	8	2		11	1.5 B					3.7		11	1	8.3	7.7
002-005	4	0	2	5	2		7	1.5 B					4.1		11	1	8.4	7.8
005-010	4	0	2	4	3		7	1.5 B					4.2		10	1	8.4	7.8
010-028	1	0	0	1	1		2	1.5 B					4.0		10	1	8.4	7.8
028-050	1	0	0	2	2		4	1.6 B					4.3		12	TR	8.3	7.8
050-080	3	0	0	3	1		4	1.59	1.62	.006		9.7	3.8	.09	14		8.3	7.7
080-100	1	0	0	1	TR		1	1.76	1.79	.006		14.2	3.4	.19	17		8.0	7.7
100-200	4	0	0	6	1		7	1.6 B					4.0		9		8.1	7.7
000-005								1.47	1.50	.007		11.7						

DEPTH	ORGANIC MATTER			IRON	PHOS	EXTRACTABLE BASES 5B4A-					ACTY	AL	CAT EXCH		RATIO	RATIO	CA	BASE SAT	
CM	6A1A ORGN CARB PCT	6B1A NITG PCT	C/N	6C2B EXT FE PCT	TOTL PCT	6N2E CA	6O2D MG	6P2B NA	6Q2B K	SUM EXTB	6H1A BACL TEA	6G1E KCL EXT	5A3A EXTB ACTY	5A6A NHAC	8D1 NHAC TO CLAY	8D3 CA TO MG	5F1 SAT NHAC PCT	5C3 EXTB ACTY PCT	5C1 NHAC PCT
						MEQ / 100 G													
000-001	.46	.036	13				3.2	TR	.2					4.2	.42				
001-002	.44	.037	12				3.3	TR	.2					4.1	.44				
002-005	.43	.038	11				3.5	TR	.2					4.1	.48				
005-010	.50	.039	13				4.0	.0	.2					4.5	.58				
010-028	.40	.039	10				3.7	.0	.1					3.8	.43				
028-050	.24	.034	7				3.7	.0	.1					3.9	.51				
050-080	.18	.021	9				3.7	TR	.1					3.5	.41				
080-100	.16	.011	15				4.0	TR	.1					2.6	.46				
100-200	.29	.014	21				4.2	.1	.1					3.5	.61				
000-005																			

DEPTH	SATURATED PASTE			NA	NA	SALT	GYP	SATURATION EXTRACT 8A1-										ATTERBERG	
CM	8E1 REST OHM-CM	8C1B PH	8A H2O PCT	9D2 ESP PCT	5E SAR	8D5 TOTL SOLU PPM	6F1A PCT	8A1A EC MMHOS/CM	6N1B CA	6O1B MG	6P1B NA	6Q1B K	6I1A CO3	6J1A HCO3	6K1C CL	6L1C SO4	6M1C NO3	4F1 LQID LMIT PCT	4F2 PLST INDX
									MEQ / LITER										
000-001		7.7	25.1			120		.64	4.8	1.9	.2	.4	.0	4.5	.2	1.4	.0		
001-002		7.8	26.0			100		.56	3.8	1.5	.2	.3	.0	3.5	.1	1.6	.0		
002-005		7.9	25.9			90		.55	3.1	1.6	.3	.3	.0	1.8	.3	1.8	.6		
005-010								.20C											
010-028								.20C											
028-050								.20C											
050-080		7.8	28.2			130		.70	3.6	2.8	.3	.3	.0	1.6	.1	4.9	.7		
080-100	2400	7.6	26.3			350		1.67	12.1	7.9	.5	.5	.0	1.5	.2	18.7	1.7	20	3 D
100-200	2700	7.7	26.8	3		310		1.47	8.5	8.6	.5	.4	.0	1.3	.2	16.2	1.1		
000-005																			

(A) CLOD OF A11, A12, AND A13 FOR BULK DENSITY AND MOISTURE RETENTION.
(B) ESTIMATE
(C) 1:2 SOIL WATER RATIO
(D) BY SOIL MECHANICS LABORATORY, USDA, LINCOLN, NE.

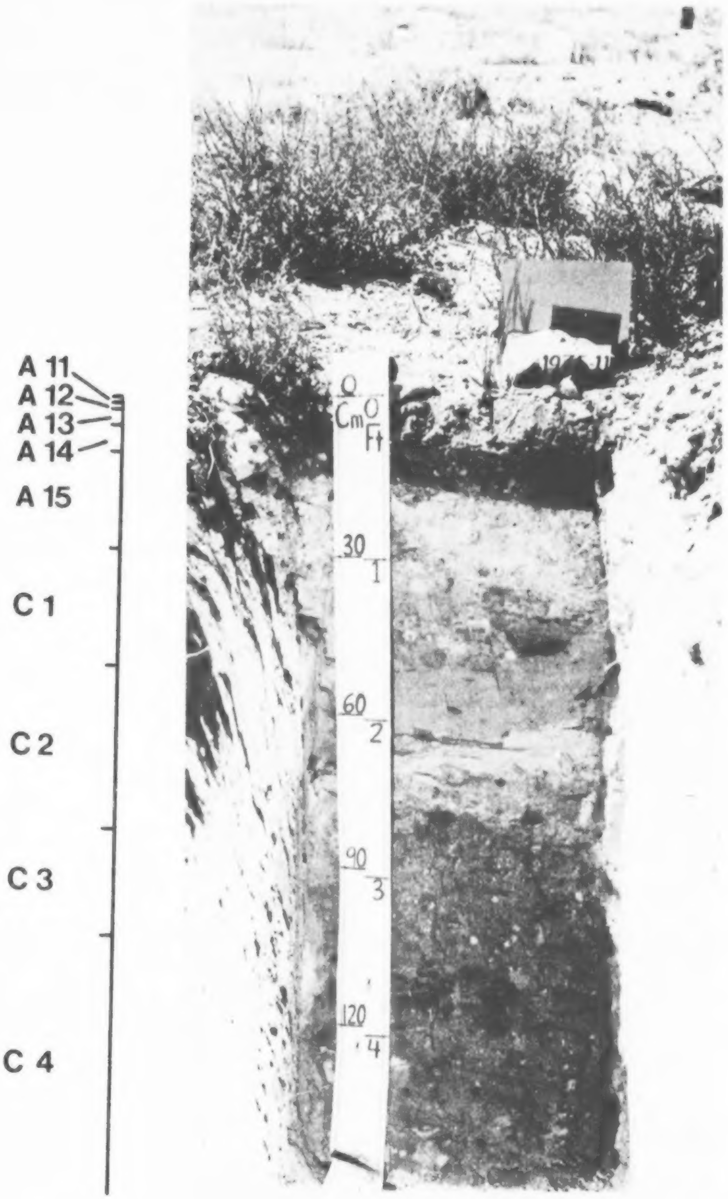
A 11
A 12
A 13
A 14
A 15
C 1
C 2
C 3
C 4
0
Cm
0
Ft
30
1
60
2
90
3
120
4

Fig. A-11. Photograph of 1975-11 soil profile.

Table A-23. Pedon description of 1973-12 soil.

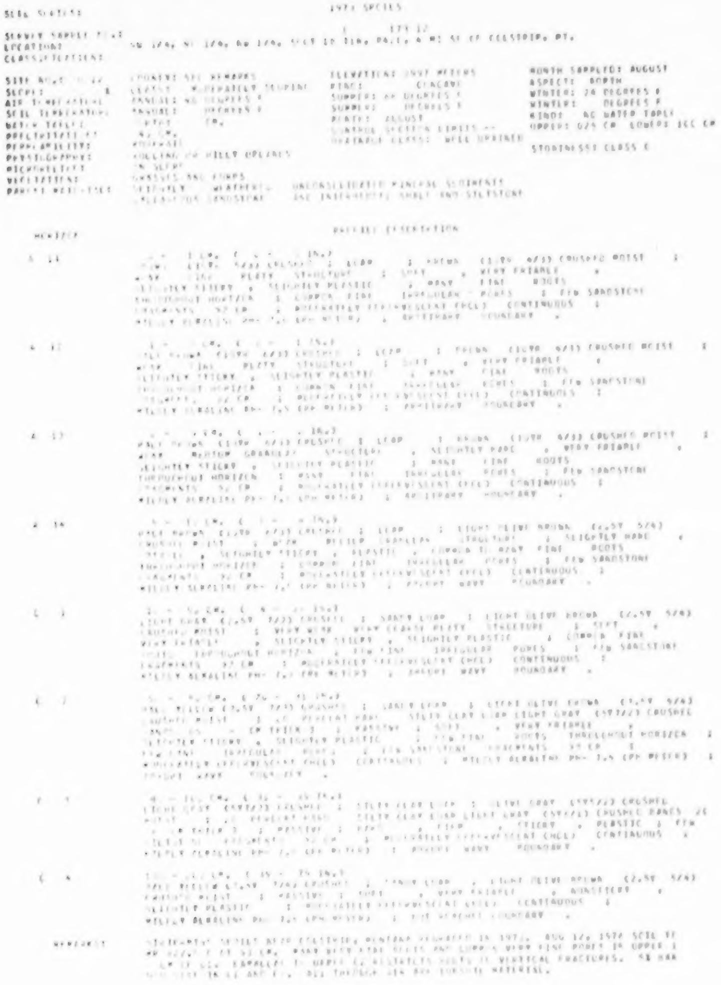

Table A-24. Laboratory analyses of 1973-12 soil.

SOIL CLASSIFICATION-

SERIES - - - - - - -REVEGETATED MINE SPOIL

SOIL NO - - - - - - S76MT-087-12   COUNTY - - - ROSEBUD

GENERAL METHODS- - -1A, 1B1B, 2A1, 2B   SAMPLE NOS. 76P0635-76P0645

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, MTSC
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA

DEPTH	HORIZON	(- - PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B - -)																RATIO
					FINE	(- - SAND - -)					(- - SILT - -)			FAML	INTR	FINE	NON-	8D1
		SAND 2-.05	SILT .05-.002	CLAY LT .002	CLAY LT .0002	VCOS 2-1	CORS 1-.5	MEDS .5-.25	FNES .25-.10	VFNS .10-.05	COSI .05-.02	FNSI .02-.002	VFSI .005-.002	TEXT SAND 2-.1	II .2-.02	CLAY TO CLAY	CO3- CLAY	15-BAR TO
CM		(- - - PCT LT 2MM - - -)														PCT	PCT	CLAY
000-001	A11	56.1	31.9	12.0		1.3	1.1	3.6	36.1	14.0	10.7	21.2		42.1			12	.81
001-002	A12	64.6	24.4	11.0		.3	.8	2.8	43.6	17.1	6.0	18.4		47.5			11	.45
002-005	A13	58.8	28.2	13.0		.4	.7	2.7	40.8	14.2	6.3	21.9		44.6			13	.38
005-010	A14	62.7	26.4	10.9		.2	.3	2.4	42.5	17.3	7.4	19.0		45.4			11	.55
010-050	C1	68.0	23.5	8.5		.2	.9	3.9	48.2	14.8	5.3	18.2		53.2			9	.56
050-080	C2	78.2	15.0	6.8		.1	.2	1.7	49.8	26.4	11.4	3.6		51.8			7	.38
080-100	C3	33.1	49.5	17.4		.2	.5	1.2	18.2	13.0	17.9	31.6		20.1			17	.44
100-200	C4	81.0	12.5	6.5		.1	.4	3.4	57.6	19.5	5.6	6.9		61.5			7	.40
000-005	(A)																	

DEPTH	(PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2)							(BULK DENSITY)			(- - WATER CONTENT - -)				CARBONATE		(- PH -)	
	VOL.	(- - WEIGHT - -)						4A1D	4A1H	4D1	4B1C	4B1C	4B2	4C1	6E1B	3A1A	8C1A	8C1E
	GT 2	GT 75	75-20	20-5	5-2	LT .074	20-2 PCT	1/3-BAR	OVEN DRY	COLE	1/10 BAR	1/3-BAR	15-BAR	WRD CM/	LT 2	LT .002	1/1 H2O	1/2 CACL
CM	PCT	PCT	(- - PCT LT 75 - -)				LT20	G/CC	G/CC		PCT	PCT	PCT	CM	PCT	PCT		
000-001	2	0	2	1	1		2	1.3 B					9.7		12		7.6	7.2
001-002	1	0	TR	1	1		2	1.5 B					4.9		13		7.8	7.3
002-005	2	0	0	1	2		3	1.5 B					5.0		13		8.1	7.3
005-010	2	0	TR	2	2		4	1.6 B					6.0		14		8.2	7.6
010-050	10	0	9	3	4		7	1.71	1.75	.007		9.8	4.8	.08	13	TR	8.2	7.7
050-080	6	0	0	4	5		9	1.7 B					2.6		14		8.6	7.9
080-100	3	0	0	4	1		5	1.7 B					7.6		18	TR	8.1	7.8
100-200	2	0	0	2	1		3	1.69	1.71	.004		8.6	2.6	.10	13		8.4	7.8
000-005								1.50	1.57	.015		15.7						

DEPTH	(ORGANIC MATTER)			IRON	PHOS	(- - EXTRACTABLE BASES 5B4A - -)					ACTY	AL	(CAT EXCH)		RATIO	RATIO	CA	(BASE SAT)	
	6A1A	6B1A	C/N	6C2B		6N2E	6O2D	6P2B	6Q2B		6H1A	6G1E	5A3A	5A6A	8D1	8D3	5F1	5C3	5C1
	ORGN CARB	NITG		EXT FE	TOTL	CA	MG	NA	K	SUM EXTB	BACL TEA	KCL EXT	EXTB ACTY	NHAC	NHAC TO	CA TO	SAT NHAC	EXTB ACTY	NHAC
CM	PCT	PCT		PCT	PCT	(- - - MEQ / 100 G - - -)									CLAY	MG	PCT	PCT	PCT
000-001	2.42	.166	15				4.7	TR	.7					8.1	.68				
001-002	.86	.053	16				3.9	TR	.4					5.0	.45				
002-005	.49	.033	15				4.6	TR	.3					4.5	.35				
005-010	.38	.027	14				4.5	TR	.3					4.4	.40				
010-050	.50	.023	22				5.3	TR	.1					4.6	.54				
050-080	.09	.014	6				4.1	TR	.1					3.0	.44				
080-100	.35	.024	15				7.0	TR	.2					4.6	.26				
100-200	.09	.009	10				3.7	TR	.1					2.7	.41				
000-005																			

DEPTH	(SATURATED PASTE)			NA	NA	SALT	GYP	(- - SATURATION EXTRACT 8A1 - -)										ATTERBERG	
	8E1	8C1B	8A	5D2	5E	8D5	6F1A	8A1A	6N1B	6O1B	6P1B	6Q1B	6I1A	6J1A	6K1C	6L1C	6M1C	4F1	4F2
	REST OHM-CM	PH	H2O	ESP	SAR	TOTL SOLU		EC MMHOS/CM	CA	MG	NA	K	CO3	HCO3	CL	SO4	NO3	LQID LMIT	PLST INDX
CM			PCT	PCT		PPM	PCT		(- - - MEQ / LITER - - -)									PCT	
000-001		6.7	47.3			870		2.22	15.8	9.8	.1	3.2	.0	20.4	.8	2.2	.0		
001-002		6.8	36.7			430		1.42	9.1	7.2	.1	1.7	.0	10.9	.3	1.5	.0		
002-005		7.0	34.9			280		1.08	6.1	4.8	.1	1.4	.0	7.0	.2	1.8	.0		
005-010		7.4	34.1			190		.81	3.9	3.6	.1	1.1	.0	4.6	.2	2.0	.0		
010-050		7.5	27.7			230		1.13	5.7	6.8	.3	.6	.0	3.2	.2	10.0	.0		
050-080								.20C											
080-100	1600	7.8	41.5			530		1.66	7.9	10.3	1.1	.8	.0	1.3	.1	19.6	1.5		NP
100-200	3000	8.0	29.1			270		1.31	5.6	7.8	.9	.6	.0	.9	.2	12.7	2.1		
000-005																			

(A) CLOD OF A11, A12, AND A13 FOR BULK DENSITY AND MOISTURE RETENTION.
(B) ESTIMATE
(C) 1:2 SOIL WATER RATIO

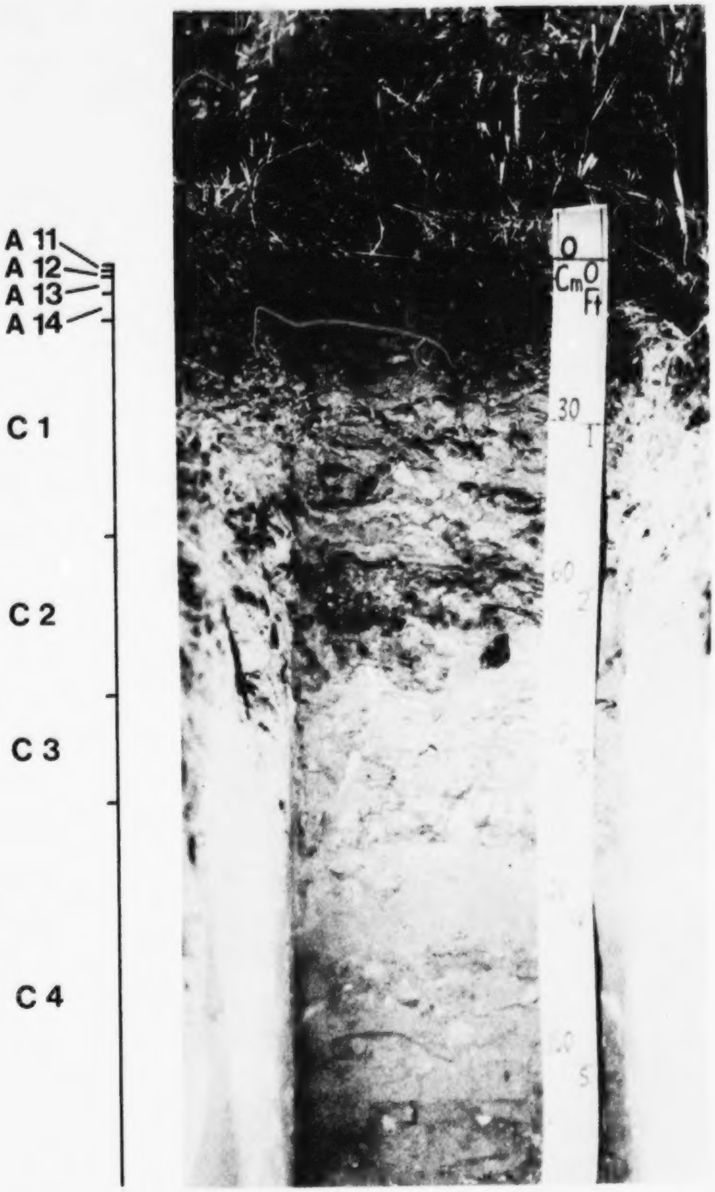
A 11
A 12
A 13
A 14
C 1
C 2
C 3
C 4
0
Cm
0
Ft
30
1
60
2
3
5

Fig. A-12. Photograph of 1973-12 soil profile.

Table A-25. Pedon description of 1972-13 soil.

```
SOIL SERIES:                                  1972 SPOILS

SURVEY SAMPLE NO.:                            C     172 13
LOCATION:           SW 1/4, NE 1/4, NE 1/4, SECT 18 T1N R42E, 4 MI SE OF COLSTRIP, MT.
CLASSIFICATION:

SITE NO.:   13     COUNTY: SEE REMARKS          ELEVATION: 1015 METERS       MONTH SAMPLED: AUGUST
SLOPE:       8     CLASS:   GENTLY SLOPING      KIND:       CONVEX           ASPECT:  WEST
AIR TEMPERATURE    ANNUAL: 46 DEGREES F         SUMMER: 68 DEGREES F         WINTER: 24 DEGREES F
SOIL TEMPERATURE   ANNUAL:    DEGREES F         SUMMER:    DEGREES F         WINTER:    DEGREES F
WATER TABLE:       DEPTH:      CM.              MONTH:  AUGUST               KIND:  NO WATER TABLE
PRECIPITATION:     36 CM.                       CONTROL SECTION LIMITS --    UPPER: 025 CM  LOWER: 100 CM
PERMEABILITY:      MODERATELY RAPID             DRAINAGE CLASS:  WELL DRAINED
PHYSIOGRAPHY:      LEVEL OR UNDULATING UPLANDS                               STONINESS: CLASS 0
MICRORELIEF:       ON SLOPE
VEGETATION:        GRASSES AND FORBS
PARENT MATERIALS:  SLIGHTLY    WEATHERED    UNCONSOLIDATED MINERAL SEDIMENTS
                   CALCAREOUS SANDSTONE     AND CALCAREOUS SILTSTONE

   HORIZON                                    PROFILE DESCRIPTION

  A 11               0 -   1 CM.  (  0 -   0 IN.)
                   BLACK   (10YR  2/0) CRUSHED  ;  FINE SANDY LOAM  ;  BLACK   (10YR  2/0) CRUSHED
                   MOIST    ;  VERY WEAK   FINE     PLATY   STRUCTURE   PARTING TO  WEAK    MEDIUM
                   GRANULAR     ;  SOFT     ,  VERY FRIABLE      ,  NONSTICKY     ,  NONPLASTIC   ;
                   MANY    FINE    ROOTS   THROUGHOUT HORIZON   ;  MANY     FINE     IRREGULAR   PORES    ;
                   NONCALCAREOUS   (HCL)   CONTINUOUS   ;  NEUTRAL PH= 6.9 (PH METER)   ;  ARBITRARY
                   BOUNDARY    .

  A 12               1 -   2 CM.  (  0 -   1 IN.)
                   YELLOWISH BROWN (10YR  5/4) CRUSHED  ;  SANDY LOAM   ;  DK. YELLOWISH BROWN (10YR  4/4)
                   CRUSHED MOIST    ;  VERY WEAK   FINE     PLATY   STRUCTURE   PARTING TO  WEAK
                   MEDIUM  GRANULAR     ;  SOFT     ,  VERY FRIABLE     ,  NONSTICKY     ,  NONPLASTIC   ;
                   MANY    FINE    ROOTS   THROUGHOUT HORIZON   ;  MANY     FINE     IRREGULAR   PORES    ;
                   MILDLY EFFERVESCENT (HCL)   CONTINUOUS   ;  NEUTRAL PH= 7.2 (PH METER)   ;
                   ARBITRARY   BOUNDARY    .

  A 13               2 -   5 CM.  (  1 -   2 IN.)
                   YELLOWISH BROWN (10YR  5/4) CRUSHED  ,  SANDY LOAM   ;  DK. YELLOWISH BROWN (10YR  4/4)
                   CRUSHED MOIST    ;  WEAK    MEDIUM  GRANULAR     STRUCTURE    ;  SOFT     ,
                   VERY FRIABLE     ,  NONSTICKY     ,  NONPLASTIC   ;  MANY     FINE     ROOTS
                   THROUGHOUT HORIZON   ;  MANY     FINE     IRREGULAR    PORES    ;  MILDLY EFFERVESCENT
                   (HCL)   CONTINUOUS   ;  MILDLY ALKALINE PH= 7.5 (PH METER)   ;  ARBITRARY
                   BOUNDARY    .

  A 14               5 -  15 CM.  (  2 -   6 IN.)
                   YELLOWISH BROWN (10YR  5/4) CRUSHED  ;  SANDY LOAM   ;  DK. YELLOWISH BROWN (10YR  4/4)
                   CRUSHED MOIST    ;  VERY WEAK   MEDIUM  GRANULAR     STRUCTURE    ;  SOFT     ,
                   VERY FRIABLE     ,  NONSTICKY     ,  NONPLASTIC   ;  MANY     FINE     ROOTS
                   THROUGHOUT HORIZON   ;  MANY     FINE     IRREGULAR    PORES    ;  MILDLY EFFERVESCENT
                   (HCL)   CONTINUOUS   ;  MILDLY ALKALINE PH= 7.5 (PH METER)   ;  ABRUPT  WAVY
                   BOUNDARY    .

  C  1              15 -  50 CM.  (  6 -  20 IN.)
                   PALE BROWN  (10YR  6/3) CRUSHED  ;  SANDY LOAM   ;  YELLOWISH BROWN (10YR  5/4)
                   CRUSHED MOIST    ;  MASSIVE  ;  SOFT     ,  VERY FRIABLE     ,  NONSTICKY     ,
                   NONPLASTIC   ;  COMMON  FINE    ROOTS   THROUGHOUT HORIZON   ;  COMMON  FINE
                   IRREGULAR   PORES    ;  MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ;
                   MILDLY ALKALINE PH= 7.6 (PH METER)   ;  ARBITRARY   BOUNDARY    .

  C  2              50 - 100 CM.  ( 20 -  39 IN.)
                   LIGHT GRAY  (10YR  7/2) CRUSHED  ;  SANDY LOAM   ;  PALE BROWN  (10YR  6/3) CRUSHED
                   MOIST    ;  20  PERCENT SOFT    SANDY LOAM  LIGHT GRAY  (2.5Y  7/1) CRUSHED BANDS  (5
                    -  CM THICK )   ;  MASSIVE  ;  SOFT     ,  VERY FRIABLE     ,  NONSTICKY     ,
                   NONPLASTIC   ;  FEW FINE    ROOTS   THROUGHOUT HORIZON   ;  FEW FINE    IRREGULAR
                   PORES    ;  MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ;  MILDLY ALKALINE PH= 7.6
                   (PH METER)   ;  ARBITRARY   BOUNDARY    .

  C  3             100 - 190 CM.  ( 39 -  75 IN.)
                   LIGHT GRAY  (10YR  7/2) CRUSHED  ;  SANDY LOAM   ;  PALE BROWN  (10YR  6/3) CRUSHED
                   MOIST    ;  20  PERCENT SOFT    SANDY LOAM  REDDISH YELLOW  (7.5YR 6/6) CRUSHED
                   BANDS  (5    -  CM THICK )   ;  MASSIVE  ;  SOFT     ,  VERY FRIABLE     ,
                   NONSTICKY     ,  NONPLASTIC   ;  FEW FINE    ROOTS   THROUGHOUT HORIZON   ;
                   MODERATELY EFFERVESCENT (HCL)   CONTINUOUS   ;  MILDLY ALKALINE PH= 7.6 (PH METER)   ;
                   NOT REACHED BOUNDARY    .

  REMARKS:         STRIP-MINE SPOILS NEAR COLSTRIP, MONTANA REGRADED IN 1972.  AUG 12, 1976  SOIL T
                   EMP =19.0 C AT 50 CM.  A11 THROUGH A14 MATERIAL ARE TOPSOIL MATERIAL.  FINELY DI
                   VIDED PYRITE AND OTHER YELLOW POWDER IN COAL FRAGMENTS.  ACID COAL ENVELOPED BY
                   1 CM BANDS OF IRON-STAINED DEPOSITS.  5MM TO 1 CM OF COAL DUST AT SOIL SURFACE (
                   BLOWING FROM COAL-LOADER).  HORIZONTAL MAT OF ROOTS AT 50 CM FOLLOWS SURFACE OF
                   GRAY SHALE BAND.  ROOT LIMITED PRIMARILY TO UPPER HALF OF C1 HORIZON.
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Table A-26. Laboratory analyses of 1972-13 soil.

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                                                                               U. S. DEPARTMENT OF AGRICULTURE
SOIL CLASSIFICATION-                                                           SOIL CONSERVATION SERVICE, MTSC
                                                                               NATIONAL SOIL SURVEY LABORATORY
SERIES - - - - - - -REVEGETATED MINE SPOIL                                     LINCOLN, NEBRASKA

SOIL NO - - - - - - S76MT-087-13    COUNTY - - -  ROSEBUD

GENERAL METHODS- - -1A, 1B1B, 2A1, 2B             SAMPLE NOS. 76P0646-76P0653

---------------------------------------------------------------------------------------------------------------------
DEPTH   HORIZON   (- - - - - - - - - - - - - PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B - - - - - - - - - - )RATIO
                                     FINE ( - - - - - - SAND - - - - - - )(- - -SILT- - - -) FAML  INTR  FINE  NON-   8D1
                   SAND  SILT  CLAY  CLAY  VCOS  CORS  MEDS  FNES  VFNS  COSI  FNSI  VFSI  TEXT   II   CLAY  CO3-   15-
                   2-    .05-  LT    LT    2-    1-    .5-   .25-  .10-  .05   .02   .005- SAND  .2-    TO   CLAY   BAR
                   .05   .002  .002  .0002 1     .5    .25   .10   .05   .02   .002  .002  2-.1  .02   CLAY           TO
  CM              (- - - - - - - - - - - - - - - - - - - PCT LT 2MM - - - - - - - - - - - - - - - -) PCT   PCT   CLAY
---------------------------------------------------------------------------------------------------------------------
000-001   A11      61.4  28.1  10.5          .0    .4   1.1  46.7  13.2  19.4   8.7        48.2                    .93
001-002   A12      79.1  11.1   9.8          .1    .4   1.8  60.1  16.7   5.4   5.7        62.4                    .38
002-005   A13      80.8  13.1   6.1          .1    .5   1.8  63.8  14.6   4.1   9.0        66.2                    .62
005-010   A14      81.6  11.5   6.9          TR    .4   1.9  62.9  16.4   4.2   7.3        65.2                    .51
010-050   C1       75.5  16.8   7.7          .3    .5   3.6  58.6  12.5   3.1  13.7        63.0                    .45
050-100   C2       71.2  25.0   3.8          .0    .4   3.4  59.6   7.8  16.7   8.3        63.4                    .55
100-200   C3
000-005       (A)

---------------------------------------------------------------------------------------------------------------------
DEPTH  (PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2)( BULK DENSITY  )(- - - -WATER  CONTENT- - - -) CARBONATE  (- -PH - -)
       VOL. (- - - - - - - - WEIGHT - - - - - - - -) 4A1D  4A1H  4D1    4B1C  4B1C  4B2   4C1       6E1B  3A1A  8C1A  8C1E
       GT    GT    75-20 20-5  5-2    LT    20-2  1/3-  OVEN  COLE   1/10  1/3-  15-   WRD       LT    LT    1/1   1/2
       2     75                      .074   PCT   BAR   DRY          BAR   BAR   BAR   CM/       2     .002  H2O   CACL
  CM   PCT   PCT   (- - - PCT LT 75 - - - ) LT20  G/CC  G/CC         PCT   PCT   PCT   CM        PCT   PCT
---------------------------------------------------------------------------------------------------------------------
000-001   1     0     0     0     2           2  1.2 B                           9.8              TR          7.3   6.3
001-002  TR     0     0    TR    TR          TR  1.4 B                           3.7               3          7.8   7.3
002-005  TR     0     0    TR    TR          TR  1.4 B                           3.8               3          8.9   7.3
005-010  TR     0     0    TR    TR          TR  1.5 B                           3.5               3          8.1   7.5
010-050   7     0     0     7     4          11  1.5 B                           3.5              11          8.4   7.7
050-100  TR     0     0    TR    TR          TR  1.5 B                           2.1              12          8.5   7.7
100-200  TR     0     0     1    TR           1  1.5 B                           2.0              12          8.3   7.6
000-005                                          1.39  1.39  .000

---------------------------------------------------------------------------------------------------------------------
DEPTH (ORGANIC MATTER   ) IRON  PHOS  (- -EXTRACTABLE BASES 5B4A- -) ACTY   AL   (CAT EXCH) RATIO RATIO  CA  (BASE SAT)
       6A1A  6B1A   C/N  6C2B          6N2E  6O2D  6P2B  6Q2B         6H1A  6G1E  5A3A  5A6A  8D1   8D3   5F1  5C3   5C1
       ORGN  NITG        EXT    TOTL   CA    MG    NA    K      SUM   BACL  KCL   EXTB  NHAC  NHAC  CA    SAT  EXTB  NHAC
       CARB              FE                                   EXTB  TEA   EXT   ACTY         TO   TO    NHAC ACTY
  CM   PCT   PCT         PCT    PCT (- - - - - - - - - - - -MEQ / 100  G- - - - - - - - - - - ) CLAY  MG    PCT  PCT   PCT
---------------------------------------------------------------------------------------------------------------------
000-001 10.00  .316   32                5.8   TR   1.1        5.2               24.9  2.37
001-002  1.72  .078   22                2.5   TR    .5                           7.0   .71
002-005  1.07  .067   16                2.4   TR    .4                           6.1  1.00
005-010   .54  .053   10                2.3   .0    .3                           5.1   .74
010-050   .12  .013    9                3.9   .0    .1                           3.7   .48
050-100   .05  .006    8                2.9   .0    .1                           2.3   .61
100-200   .07  .005   14                2.9   TR    TR                           2.2
000-005

---------------------------------------------------------------------------------------------------------------------
DEPTH  (SATURATED PASTE)  NA    NA   SALT  GYP  (- - - - - - - - - - SATURATION EXTRACT 8A1- - - - - - - - - - ) ATTERBERG
        8E1  8C1B  8A    5D2   5E    8D5   6F1A  8A1A  6N1B  6O1B  6P1B  6Q1B  6I1A  6J1A  6K1C  6L1C  6M1C   4F1  4F2
        REST PH    H2O   ESP   SAR   TOTL        EC    CA    MG    NA    K     CO3   HCO3  CL    SO4   NO3    LQID PLST
        OHM-                         SOLU        MMHOS/                                                     LMIT INDX
  CM    CM         PCT   PCT         PPM   PCT   CM   ( - - - - - - - - - MEQ / LITER - - - - - - - - - - ) PCT
---------------------------------------------------------------------------------------------------------------------
000-001        6.7  60.5               1100       2.09  15.0   8.4    .1   4.0    .0  18.4   1.9   2.0    .0
001-002        7.3  33.9                240        .95   7.0   2.6    .1   1.4    .0   7.2    .9    .7    .0
002-005        7.4  31.5                240       1.01   7.8   2.9    .1   1.1    .0   7.8   1.1    .7    .0
005-010        7.8  31.0                120        .56   3.8   1.7    .0    .5    .0   4.2    .3    .3    .0
010-050                                            .20C                                                          NP
050-100  6100  8.1                                 .20C
100-200  3200  8.0  28.8           1    280       1.34   6.3   6.6   2.2    .3    .0    .8    .7  16.7    .0
000-005
---------------------------------------------------------------------------------------------------------------------
(A)  CLOD OF A11, A12, AND A13 FOR BULK DENSITY AND MOISTURE RETENTION.
(B)  ESTIMATE
(C)  1:2 SOIL WATER RATIO
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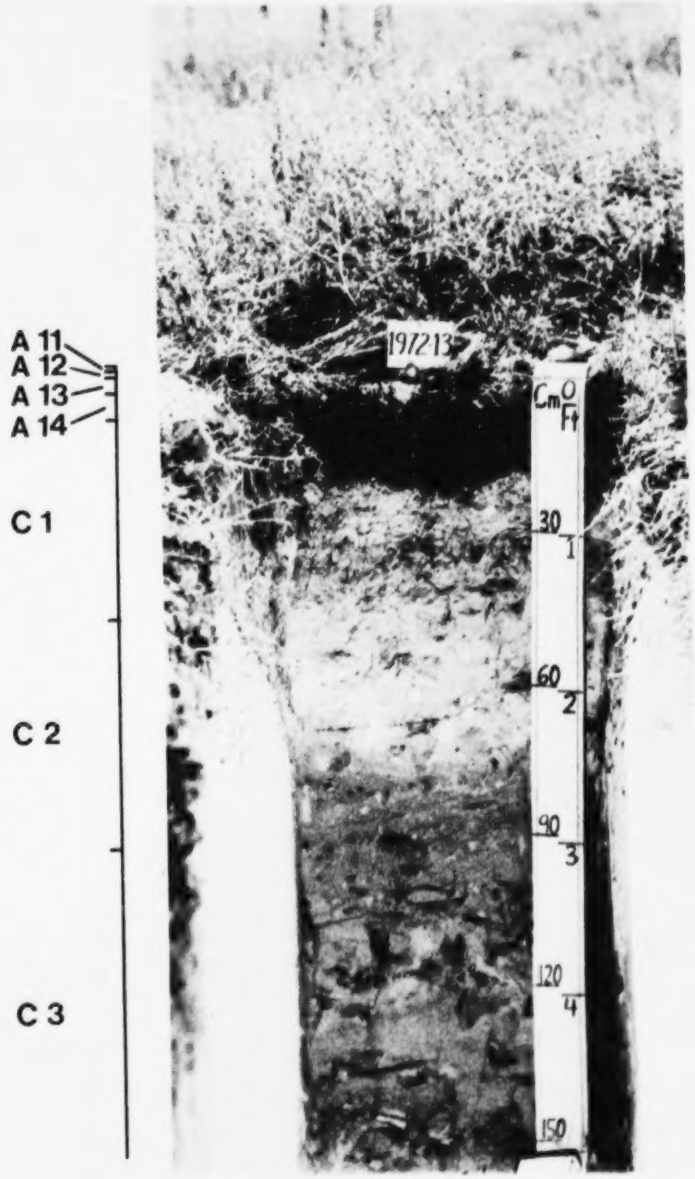
A 11
A 12
A 13
A 14
C 1
C 2
C 3
1972-13
Cm 0 Ft
30
1
60
2
90
3
120
4
150

Fig. A-13. Photograph of 1972-13 soil profile.

Table A-27. Pedon description of 1969-14 soil.

```
SOIL SERIES:                          1969 SPOILS

SURVEY SAMPLE NO.:                     C    173 14
LOCATION:          SE 1/4, NW 1/4, NW 1/4, SECT 17 T1N, R42E, 4 MI SE OF COLSTRIP, MT.
CLASSIFICATION:

SITE NO.:  C 14    COUNTY: SEE REMARKS          ELEVATION: 0981 METERS        MONTH SAMPLED: AUGUST
SLOPE:          1  CLASS:  NEARLY LEVEL         KIND:        CONCAVE          ASPECT:  NORTHWEST
AIR TEMPERATURE:   ANNUAL: 46 DEGREES F         SUMMER: 68 DEGREES F          WINTER: 24 DEGREES F
SOIL TEMPERATURE:  ANNUAL:    DEGREES F         SUMMER:    DEGREES F          WINTER:    DEGREES F
WATER TABLE:       DEPTH:     CM.               MONTH:  AUGUST                KIND:  NO WATER TABLE
PRECIPITATION:     387 CM.                      CONTROL SECTION LIMITS --     UPPER: 025 CM  LOWER: 100 CM
PERMEABILITY:      MODERATELY RAPID             DRAINAGE CLASS:  WELL DRAINED
PHYSIOGRAPHY:      LEVEL OR UNDULATING UPLANDS                                STONINESS: CLASS 0
MICRORELIEF:       IN SLOPE
VEGETATION:        GRASSES AND FORBS AND SHRUBS
PARENT MATERIAL:   SLIGHTLY   WEATHERED   UNCONSOLIDATED MINERAL SEDIMENTS
                   CALCAREOUS SANDSTONE    AND CALCAREOUS SILTSTONE

  HORIZON                                PROFILE DESCRIPTION

  A 11              0 -   1 CM.  (  0 -   0 IN.)
                  LIGHT GRAY  (10YR  7/1) CRUSHED  ;  FINE SANDY LOAM  ;  GRAYISH BROWN   (10YR  5/2)
                  CRUSHED MOIST    ;  FEW TO COMMON   COARSE  PROMINENT   STRONG BROWN    (7.5YR 5/8)
                  CRUSHED MOTTLES  ;  VERY WEAK    FINE    PLATY   STRUCTURE    ;  SOFT    ,
                  VERY FRIABLE     ,  NONSTICKY     ,  SLIGHTLY PLASTIC     ;  MANY    FINE    ROOTS
                  THROUGHOUT HORIZON   ;  MANY    FINE    IRREGULAR   PORES    ;  10  PERCENT
                  MIXED SEDIMENTARY   FRAGMENTS   >2 MM    ;  MILDLY EFFERVESCENT (HCL)   CONTINUOUS   ;
                  SLIGHTLY ACID   PH- 6.3 (PH METER)   ;  ARBITRARY   BOUNDARY   .

  A 12              1 -   2 CM.  (  0 -   1 IN.)
                  LIGHT GRAY  (10YR  7/2) CRUSHED  ;  SANDY LOAM   ;  GRAYISH BROWN   (10YR  5/2)
                  CRUSHED MOIST    ;  FEW TO COMMON   COARSE  PROMINENT   STRONG BROWN    (7.5YR 5/8)
                  CRUSHED MOTTLES  ;  VERY WEAK    FINE    PLATY   STRUCTURE    ;  SOFT    ,
                  VERY FRIABLE     ,  NONSTICKY     ,  SLIGHTLY PLASTIC     ;  MANY    FINE    ROOTS
                  THROUGHOUT HORIZON   ;  MANY    FINE    IRREGULAR   PORES    ;  10  PERCENT
                  MIXED SEDIMENTARY   FRAGMENTS   >2 MM    ;  MILDLY EFFERVESCENT (HCL)   CONTINUOUS   ;
                  MILDLY ALKALINE PH- 7.5 (PH METER)   ;  ARBITRARY   BOUNDARY   .

  A 13              2 -   5 CM.  (  1 -   2 IN.)
                  LIGHT BROWNISH GRAY (10YR  6/2) CRUSHED  ;  FINE SANDY LOAM  ;  GRAYISH BROWN
                  (10YR  5/2) CRUSHED MOIST    ;  FEW TO COMMON   COARSE  PROMINENT   STRONG BROWN
                  (7.5YR 5/8) CRUSHED MOTTLES  ;  VERY WEAK    FINE    PLATY    STRUCTURE    ;  SOFT    ,
                  VERY FRIABLE     ,  NONSTICKY     ,  SLIGHTLY PLASTIC     ;  MANY    FINE    ROOTS
                  THROUGHOUT HORIZON   ;  MANY    FINE    IRREGULAR   PORES    ;  1  PERCENT
                  MIXED SEDIMENTARY   FRAGMENTS   >2 MM    ;  MILDLY EFFERVESCENT (HCL)   CONTINUOUS   ;
                  MILDLY ALKALINE PH- 7.4 (PH METER)   ;  CLEAR    WAVY    BOUNDARY   .

  C  1              5 -  15 CM.  (  2 -   6 IN.)
                  LIGHT BROWNISH GRAY (10YR  6/2) CRUSHED  ;  SANDY LOAM   ;  GRAYISH BROWN   (10YR  5/2)
                  CRUSHED MOIST    ;  FEW TO COMMON   COARSE  PROMINENT   STRONG BROWN    (7.5YR 5/8)
                  CRUSHED MOTTLES  ;  VERY WEAK    FINE    PLATY   STRUCTURE    ;  SOFT    ,
                  VERY FRIABLE     ,  SLIGHTLY STICKY  ,  SLIGHTLY PLASTIC     ;  MANY    FINE
                  ROOTS   THROUGHOUT HORIZON   ;  MANY    FINE    IRREGULAR   PORES    ;  1  PERCENT
                  MIXED SEDIMENTARY   FRAGMENTS   >2 MM    ;  MILDLY EFFERVESCENT (HCL)   CONTINUOUS   ;
                  NEUTRAL PH- 7.3 (PH METER)   ;  ARBITRARY   BOUNDARY   .

  C  2             15 -  50 CM.  (  6 -  20 IN.)
                  LIGHT GRAY  (10YR  7/2) CRUSHED  ;  SANDY LOAM   ;  LIGHT BROWNISH GRAY (10YR  6/2)
                  CRUSHED MOIST    ;  FEW TO COMMON   COARSE  PROMINENT   STRONG BROWN    (7.5YR 5/8)
                  CRUSHED MOTTLES  ;  20  PERCENT VERY HARD   BLACK   (10YR  2/0) CRUSHED
                  CHARCOAL PANES 10    -  CM THICK )   ;  MASSIVE   ;  SOFT     ,  VERY FRIABLE     ,
                  NONSTICKY     ,  NONPLASTIC   ;  COMMON  FINE    ROOTS   THROUGHOUT HORIZON    ;
                  MANY    FINE    IRREGULAR    PORES    ;   1  PERCENT MIXED SEDIMENTARY   FRAGMENTS
                  >2 MM    ;  MILDLY EFFERVESCENT (HCL)   CONTINUOUS    ;  MILDLY ALKALINE PH- 7.5
                  (PH METER)   ;  ARBITRARY   BOUNDARY   .

  C  3             50 - 120 CM.  ( 20 -  48 IN.)
                  WHITE    (10YR  8/1) CRUSHED  ;  LOAMY SAND   ;  LIGHT GRAY  (10YR  6/1) CRUSHED
                  MOIST    ;  FEW COARSE  PROMINENT   STRONG BROWN    (7.5YR 5/8) CRUSHED MOTTLES  ;  20
                  PERCENT VERY HARD   BLACK   (10YR  2/0) CRUSHED CHARCOAL BANDS 10    -  CM THICK )   ;
                  MASSIVE   ;  SOFT     ,  VERY FRIABLE     ,  NONSTICKY     ,  NONPLASTIC    ;  FEW
                  FINE    ROOTS   THROUGHOUT HORIZON   ;  FEW FINE    TUBULAR CONTINUOUS  PORES    ;  1
                  PERCENT MIXED SEDIMENTARY   FRAGMENTS   >2 MM    ;  MILDLY EFFERVESCENT (HCL)
                  CONTINUOUS   ;  MILDLY ALKALINE PH- 7.6 (PH METER)   ;  ARBITRARY   BOUNDARY   .

  C  4            120 - 200 CM.  ( 48 -  79 IN.)
                  LIGHT GRAY  (10YR  7/1) CRUSHED  ;  LOAMY SAND   ;  LIGHT BROWNISH GRAY (10YR  6/2)
                  CRUSHED MOIST    ;  LIGHT GRAY  (10YR  7/2) CRUSHED  ;  PALE BROWN  (10YR  6/3)
                  CRUSHED MOIST    ;  MASSIVE   ;  SOFT     ,  VERY FRIABLE     ,  NONSTICKY     ,
                  NONPLASTIC   ;  FEW FINE    ROOTS   THROUGHOUT HORIZON   ;  FEW FINE
                  TUBULAR CONTINUOUS  PORES    ;  10  PERCENT MIXED SEDIMENTARY   FRAGMENTS   >2 MM    ;
                  MILDLY EFFERVESCENT (HCL)   CONTINUOUS   ;  MILDLY ALKALINE PH- 7.6 (PH METER)   ;
                  NOT REACHED BOUNDARY   .

   REMARKS:       STRIP-MINE SPOILS NEAR COLSTRIP, MONTANA REGRADED IN 1969.  AUG. 12, 1976 SOIL T
                  EMP = 19.5 C AT 50 CM.  ROOTS IN C4 PROLIFERATE IN SOFT COAL FRAGMENTS.  MANY VE
                  RY FINE ROOTS IN UPPER HALF OF C2.  MOSS MAT 1 CM THICK COVERS SURFACE.  POCKETS
                   OF HEAVY LOAM MATERIAL COMPRISE 10% OF VOLUME.  20% COAL TO A DEPTH OF ONE METE
                  R.  CONCENTRIC IRON-STAINED 2 CM. RINGS (7.5 YR 5/8) ARE ASSOCIATED WITH COAL PO
                  CKETS.  THE RING IS SEPARATED FROM THE COAL BY A 1 MM LAYER OF GYPSUM.  AFFECTED
                   COAL CONTAINS PYRITE.  PH OF THE AFFECTED COAL IS 2.1, THE INSIDE OF THE RING I
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Table A-28. Laboratory analyses of 1969-14 soil.

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SOIL CLASSIFICATION-                                                          U. S. DEPARTMENT OF AGRICULTURE
                                                                              SOIL CONSERVATION SERVICE, MTSC
SERIES - - - - - - -RECLAIMED MINE SPOIL                                      NATIONAL SOIL SURVEY LABORATORY
                                                                              LINCOLN, NEBRASKA
SOIL NO - - - - - - S76MT-087-14    COUNTY - - -  ROSEBUD

GENERAL METHODS- - -1A, 1B1B, 2A1, 2B                SAMPLE NOS. 76P0654-76P0665

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DEPTH   HORIZON (- - - - - - - - - - - - - PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B - - - - - - - - - - )RATIO
                              FINE ( - - - - - - SAND - - - - - - )(- - -SILT- - - -)  FAML  INTR  FINE  NON-   8D1
                  SAND  SILT  CLAY  CLAY  VCOS  CORS  MEDS  FNES  VFNS  COSI  FNSI  VFSI  TEXT    II  CLAY  CO3-   15-
                    2-  .05-    LT    LT    2-    1-   .5-  .25-  .10-   .05   .02 .005-  SAND   .2-    TO  CLAY   BAR
                   .05  .002  .002 .0002     1    .5   .25   .10   .05   .02  .002  .002  2-.1   .02  CLAY          TO
  CM            (- - - - - - - - - - - - - - - - - - PCT LT 2MM - - - - - - - - - - - - - - - - - -)   PCT   PCT  CLAY
-----------------------------------------------------------------------------------------------------------------------
000-001  A11      49.5  35.9  14.6          .4   1.3   2.6  26.7  16.5  12.2  23.7        33.0                    1.32
001-002  A12      52.2  34.0  13.8          .3    .9   2.4  33.6  15.0  12.9  21.1        37.2                     .61
002-005  A13      56.0  28.6  15.4          .3    .8   2.1  36.5  16.3   7.3  21.3        39.7                     .41
005-010  C1       60.2  29.6  10.2          .4   1.1   2.7  41.5  12.5  11.3  18.3        47.7                     .65
010-050  C2       78.7  16.0   5.3          .1    .4   4.9  59.7  13.6   4.2  11.8        65.1                     .47
050-100  C3       81.4  13.7   4.9          TR    .2   3.4  65.5  12.3   3.8   9.9        69.1                     .47
100-200  C4       86.6   5.3   8.1                                                   5.4        71.5                     .37
000-005      (A)
-------  COAL
-------  COAL
-------  COAL
-------  COAL

-----------------------------------------------------------------------------------------------------------------------
DEPTH  (PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2)(  BULK DENSITY  )(- - - -WATER  CONTENT- - - -) CARBONATE  (- -PH - -)
          VOL. (- - - - - - - - WEIGHT - - - - - - - -)  4A1D  4A1H   4D1  4B1C  4B1C   4B2   4C1  6E1B  3A1A  8C1A  8C1E
            GT    GT 75-20  20-5   5-2    LT  20-2  1/3-  OVEN  COLE  1/10  1/3-   15-   WRD    LT    LT   1/1   1/2
             2    75                    .074   PCT   BAR   DRY         BAR   BAR   BAR   CM/     2  .002   H2O  CACL
  CM       PCT   PCT (- - - PCT LT 75 - - -)  LT20  G/CC  G/CC         PCT   PCT   PCT    CM   PCT   PCT
-----------------------------------------------------------------------------------------------------------------------
000-001      2     0     0     1     2           3 1.2 B                          19.3              10           7.4   6.9
001-002      2     0     0     1     2           3 1.3 B                           8.4              11           7.3   7.1
002-005      2     0     0     2    14          16 1.3 B                           6.3              12           7.3   7.2
005-010      5     0     1     5     4           9  1.38  1.47  .020        16.5   6.6   .13         3           7.2   7.1
010-050      1     0     0     1    TR           1  1.66  1.67  .002         9.4   2.5   .11        10           8.0   7.7
050-100      2     0     0     2     1           3 1.6 B                           7.3              11           8.1   7.6
100-200      6     0     4     3     2           5  1.47  1.48  .002         5.9   3.0   .10        10           7.9   7.6
000-005                                             1.30  1.39  .023        18.3
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DEPTH (ORGANIC MATTER  ) IRON  PHOS (- -EXTRACTABLE BASES 5B4A- -) ACTY    AL  (CAT EXCH) RATIO RATIO   CA  (BASE SAT)
        6A1A  6B1A   C/N  6C2B        6N2E  6O2D  6P2B  6Q2B        6H1A  6G1F  5A3A  5A6A   8D1   8D3   5F1   5C3   5C1
        ORGN  NITG         EXT  TOTL    CA    MG    NA     K   SUM  BACL   KCL  EXTR  NHAC  NHAC    CA   SAT  EXTR  NHAC
        CARB                FE                                EXTB   TEA   EXT  ACTY          TO    TO  NHAC  ACTY
  CM     PCT   PCT         PCT   PCT (- - - - - - - - - - -MEQ / 100 G- - - - - - - - - - -)  CLAY    MG   PCT   PCT   PCT
-----------------------------------------------------------------------------------------------------------------------
000-001  6.26  .299    21                     5.4    TR    .6                          24.3
001-002  2.63  .110    24                     4.8    .0    .3                          12.3   .89
002-005  1.82  .068    27                     4.7    TR    .2                           9.1   .59
005-010  2.43  .082    30                     4.8    TR    .1                          13.3  1.30
010-050   .26  .018    14                     4.6    TR    .1                           3.4
050-100   .27  .013    21                     3.7    TR    .1                           2.5   .51
100-200   .46  .021    22                     4.3    TR    .1                           3.8
000-005
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DEPTH  (SATURATED PASTE)   NA    NA  SALT   GYP (- - - - - - - - - SATURATION EXTRACT 8A1- - - - - - - - - -) ATTERBERG
         8E1  8C1B    8A   5D2    5E   8D5  6F1A  8A1A  6N1B  6O1B  6P1B  6Q1B  6I1A  6J1A  6K1C  6L1C  6M1C   4F1   4F2
        REST    PH   H2O   ESP   SAR  TOTL          EC    CA    MG    NA     K   CO3  HCO3    CL   SO4   NO3  LQID  PLST
        OHM-                        SOLU      MMHOS/                                                        LMIT  INDX
  CM      CM         PCT   PCT         PPM   PCT    CM (- - - - - - - - - - MEQ / LITER - - - - - - - - - - -)   PCT
-----------------------------------------------------------------------------------------------------------------------
000-001          6.7  87.0              2000     0  2.50  25.1   8.5    .1   1.8    .0  13.4    .6  17.6    .0
001-002          6.8  40.1               970     0  2.65  27.4   9.3    .0   1.1    .0   6.8    .9  26.8    .0
002-005          6.8  36.0              1100     0  2.99  35.4   9.5    .1   1.0    .0   6.1    .8  38.6    .0
005-010          6.6  34.5               990        2.98  33.5  10.5    .1    .6    .0   4.2    .6  45.0    .0
010-050          7.4  28.4               970     0  3.37  26.6  26.4    .2    .4    .0   2.0    .2  56.5    .0
050-100  2200    7.6  28.6               560        2.19  12.7  17.3    .3    .3    .0    .4    .3  31.3    .0
100-200  1500    7.4  27.8               890     0  3.17  24.8  24.0   1.1    .3    .0   1.1    .3  51.6    .0          NP
000-005
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(A)  CLOD OF A11, A12, AND A13 FOR BULK DENSITY AND MOISTURE RETENTION.
(B)  ESTIMATE
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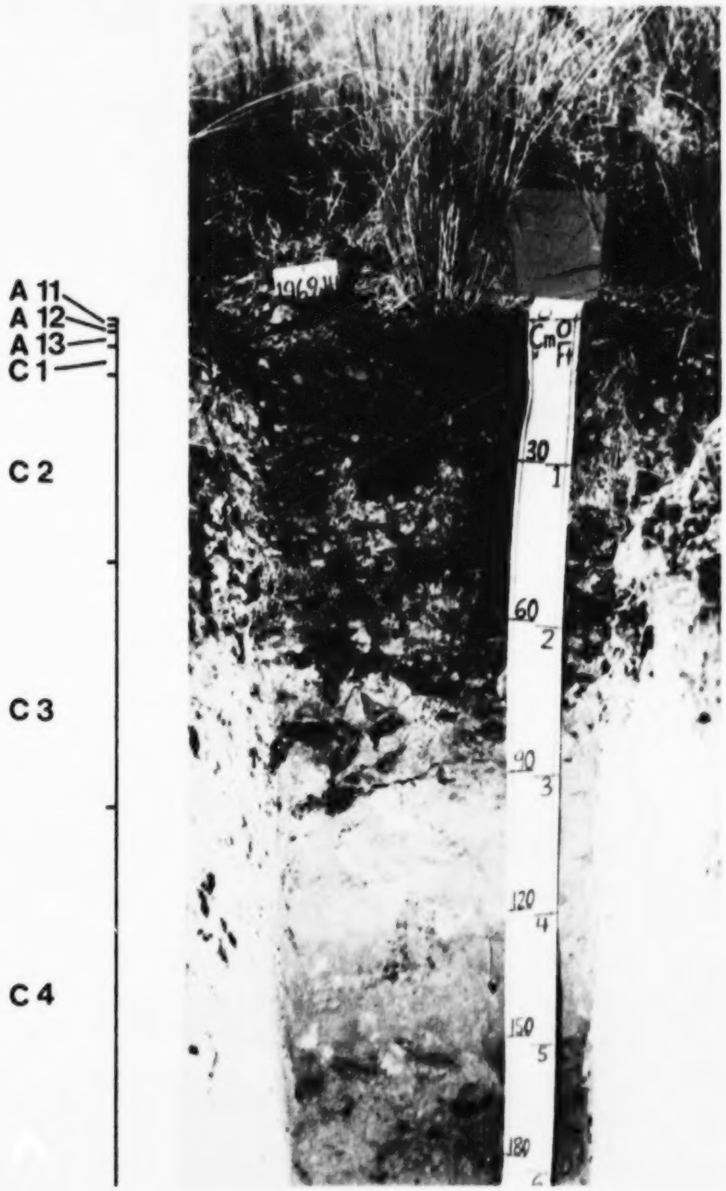
A 11
A 12
A 13
C 1
C 2
C 3
C 4
1969-14
Cm
Ft
30
1
60
2
90
3
120
4
150
5
180
6

Fig. A-14. Photograph of 1969-14 soil profile.

Table A-29. Pedon description of 1970-15 soil.

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SOIL SERIES:                                  1970 SPOILS

SURVEY SAMPLE NO.:                              0     173 15
LOCATION:          NE 1/4, NE 1/4, SW 1/4, SECT 17 T1N, R42E, 5 MI SE OF COLSTRIP, MT.
CLASSIFICATION:

SITE NO.:  0 15    COUNTY: SEE REMARKS         ELEVATION: 0981 METERS      MONTH SAMPLED: AUGUST
SLOPE:         4   CLASS:  GENTLY SLOPING      KIND:        CONCAVE        ASPECT:  SOUTHEAST
AIR TEMPERATURE:   ANNUAL: 46 DEGREES F        SUMMER: 68 DEGREES F        WINTER: 24 DEGREES F
SOIL TEMPERATURE:  ANNUAL:    DEGREES F        SUMMER:    DEGREES F        WINTER:    DEGREES F
WATER TABLE:       DEPTH:     CM.              MONTH:  AUGUST              KIND:  NO WATER TABLE
PRECIPITATION:     340 CM.                     CONTROL SECTION LIMITS --   UPPER: 025 CM  LOWER: 100 CM
PERMEABILITY:      MODERATELY RAPID            DRAINAGE CLASS:  WELL DRAINED
PHYSIOGRAPHY:      LEVEL OR UNDULATING UPLANDS                             STONINESS: CLASS 0
MICRORELIEF:       ON SLOPE
VEGETATION:        GRASSES AND FORBS
PARENT MATERIAL:   SLIGHTLY    WEATHERED   UNCONSOLIDATED MINERAL SEDIMENTS
                   CALCAREOUS SANDSTONE    AND CALCAREOUS SILTSTONE

 HORIZON                                PROFILE DESCRIPTION

 A  11               0 -   1 CM.  (  0 -   0 IN.)
                   YELLOWISH BROWN (10YR  5/4) CRUSHED  ;  FINE SANDY LOAM  ;  DK. YELLOWISH BROWN
                   (10YR  4/4) CRUSHED MOIST    ;  WEAK     FINE     GRANULAR    STRUCTURE    ;  SOFT     ,
                   VERY FRIABLE     ,  NONSTICKY     ,  NONPLASTIC    ;  MANY     FINE     ROOTS
                   MATTED AROUND STONES AND PEBBLES     ;  MANY    FINE     IRREGULAR    PORES    ;
                   MODERATELY EFFERVESCENT (HCL)   CONTINUOUS    ;  MODERATELY ALKALINE PH- 8.0
                   (CRORTHYMOL BLUE)    ;  ARBITRARY    BOUNDARY    .

 A  12               1 -   2 CM.  (  0 -   1 IN.)
                   YELLOWISH BROWN (10YR  5/4) CRUSHED  ;  FINE SANDY LOAM  ;  DK. YELLOWISH BROWN
                   (10YR  4/4) CRUSHED MOIST    ;  WEAK     FINE     GRANULAR    STRUCTURE    ;  SOFT     ,
                   VERY FRIABLE     ,  NONSTICKY     ,  NONPLASTIC    ;  MANY     FINE     ROOTS
                   MATTED AROUND STONES AND PEBBLES     ;  MANY    FINE     IRREGULAR    PORES    ;
                   MODERATELY EFFERVESCENT (HCL)   CONTINUOUS    ;  MODERATELY ALKALINE PH- 8.2
                   (CRORTHYMOL BLUE)    ;  ARBITRARY    BOUNDARY    .

 A  13               2 -   5 CM.  (  1 -   2 IN.)
                   YELLOWISH BROWN (10YR  5/4) CRUSHED  ;  FINE SANDY LOAM  ;  DK. YELLOWISH BROWN
                   (10YR  4/4) CRUSHED MOIST    ;  WEAK     FINE     GRANULAR    STRUCTURE    ;  SOFT     ,
                   VERY FRIABLE     ,  NONSTICKY     ,  NONPLASTIC    ;  MANY     FINE     ROOTS
                   MATTED AROUND STONES AND PEBBLES     ;  MANY    FINE     IRREGULAR    PORES    ;
                   MODERATELY EFFERVESCENT (HCL)   CONTINUOUS    ;  MODERATELY ALKALINE PH- 8.2
                   (CRORTHYMOL BLUE)    ;  ABRUPT  BROKEN  BOUNDARY    .

 C   1               5 -  10 CM.  (  2 -   4 IN.)
                   LIGHT BROWNISH GRAY (10YR  6/2) CRUSHED  ;  FINE SANDY LOAM  ;  BROWN   (10YR  5/3)
                   CRUSHED MOIST    ;  WEAK    PLATY    STRUCTURE     ;  SLIGHTLY HARD     ,
                   VERY FRIABLE     ,  NONSTICKY     ,  NONPLASTIC    ;  MANY     FINE     ROOTS
                   MATTED AROUND STONES AND PEBBLES     ;  COMMON  FINE     IRREGULAR    PORES    ;  FEW
                   SILTSTONE    FRAGMENTS    >2 CM     ;  MODERATELY EFFERVESCENT (HCL)   CONTINUOUS    ;
                   MODERATELY ALKALINE PH- 8.4 (CRORTHYMOL BLUE)     ;  ARBITRARY    BOUNDARY    .

 C   2              10 -  50 CM.  (  4 -  20 IN.)
                   LIGHT GRAY  (10YR  7/2) CRUSHED  ;  SANDY LOAM   ;  PALE BROWN  (10YR  6/3) CRUSHED
                   MOIST    ;  10  PERCENT VERY HARD   SANDY LOAM  YELLOWISH BROWN (10YR  5/6) CRUSHED
                   POCKETS OF CONTRASTING MATERIAL(S    -  CM THICK )  ;  MASSIVE  ;  SLIGHTLY HARD     ,
                   FRIABLE  ,  NONSTICKY     ,  NONPLASTIC    ;  COMMON  FINE     ROOTS
                   THROUGHOUT HORIZON    ;  FEW FINE     TUBULAR CONTINUOUS  PORES     ;
                   MODERATELY EFFERVESCENT (HCL)   CONTINUOUS    ;  STRONGLY ALKALINE    PH- 8.6
                   (CRORTHYMOL BLUE)    ;  ARBITRARY    BOUNDARY    .

 C   3              50 - 100 CM.  ( 20 -  39 IN.)
                   LIGHT GRAY  (10YR  7/2) CRUSHED  ;  SANDY LOAM   ;  PALE BROWN  (10YR  6/3) CRUSHED
                   MOIST    ;  10  PERCENT VERY HARD   SANDY LOAM  YELLOWISH BROWN (10YR  5/6) CRUSHED
                   POCKETS OF CONTRASTING MATERIAL(S    -  CM THICK )  ;  MASSIVE  ;  SLIGHTLY HARD     ,
                   VERY FRIABLE     ,  NONSTICKY     ,  NONPLASTIC    ;  COMMON  FINE     ROOTS
                   THROUGHOUT HORIZON    ;  FEW FINE     TUBULAR CONTINUOUS  PORES     ;  FEW SILTSTONE
                   FRAGMENTS    >2 CM    ;  MODERATELY EFFERVESCENT (HCL)    CONTINUOUS    ;
                   STRONGLY ALKALINE    PH- 8.8 (CRORTHYMOL BLUE)     ;  ARBITRARY    BOUNDARY    .

 C   4             100 - 200 CM.  ( 39 -  79 IN.)
                   LIGHT GRAY  (10YR  7/2) CRUSHED  ;  SANDY LOAM    ;  BROWN    (10YR  5/3) CRUSHED
                   MOIST    ;  MASSIVE  ;  SLIGHTLY HARD     ,  FRIABLE  ,  NONSTICKY     ,  NONPLASTIC    ;
                   COMMON  FINE     ROOTS    THROUGHOUT HORIZON    ;  FEW FINE     TUBULAR CONTINUOUS
                   PORES    ;  20  PERCENT SANDSTONE   FRAGMENTS    >2 CM     ;  MODERATELY EFFERVESCENT
                   (HCL)   CONTINUOUS    ;  STRONGLY ALKALINE    PH- 8.6 (CRORTHYMOL BLUE)     ;
                   NOT REACHED BOUNDARY    .

   REMARKS:        STRIP-MINE SPOILS NEAR COLSTRIP, MONTANA REGRADED IN 1970.  AUG 11, 1976 SOIL TE
                   MP = 21.0 C AT 50 CM. A11 THROUGH A13 CONSISTS OF TOPSOIL MATERIAL.  10% SILTSTO
                   NE AND SANDSTONE FRAGMENTS.  LITTLE COAL OBSERVED.  FEW FERRUGINOUS CONCRETIONS
                   (6 CM).  COMMON FINE ROOTS IN UPPER HALF OF C2.  THYMOL BLUE GIVES PH 0.5 TO 1.0
                   HIGHER THAN METER.
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Table A-30. Laboratory analyses of 1970-15 soil.

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, MTSC
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA

SOIL CLASSIFICATION-

SERIES - - - - - - -REVEGETATED MINE SPOIL

SOIL NO - - - - - - S76MT-087-15   COUNTY - - - ROSEBUD

GENERAL METHODS- - -1A, 1B1B, 2A1, 2B   SAMPLE NOS. 76P0666-76P0674

DEPTH CM	HORIZON	SAND 2-.05	SILT .05-.002	CLAY LT .002	FINE CLAY LT .0002	VCOS 2-1	CORS 1-.5	MEDS .5-.25	FNES .25-.10	VFNS .10-.05	COSI .05-.02	FNSI .02-.002	VFSI .005-.002	FAML TEXT SAND 2-.1	INTR II .2-.02	FINE CLAY TO CLAY PCT	NON-CO3-CLAY PCT	RATIO 8D1 15-BAR TO CLAY
		PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B — PCT LT 2MM																
000-001	A11	78.4	15.6	6.0		.2	.6	2.1	54.2	21.3	12.0	3.6		57.1				1.72
001-002	A12	81.4	12.7	5.9		TR	.2	1.5	53.0	26.7	9.5	3.2		54.7				.71
002-005	A13	56.8	38.3	4.9		.1	.2	.9	37.0	18.6	32.2	6.1		38.2				.67
005-010	C1	65.9	26.0	8.1		.2	.3	1.5	40.9	23.0	11.4	14.6		42.9				.36
010-050	C2	60.4	30.3	9.3		.2	.6	3.1	37.9	18.6	12.1	18.2		41.8				.36
050-100	C3	71.2	21.5	7.3		.2	.5	3.5	46.2	20.8	8.6	12.9		50.4				.45
100-200	C4	66.2	27.3	6.5		.2	.7	2.6	38.2	24.5	16.8	10.5		41.7				.55
100-200	SHALE	7.9	64.4	27.7		1.4	2.1	1.0	2.1	1.3	6.1	58.3		6.6				
100-200	SHALE																	

DEPTH CM	PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2 — VOL. GT 2 PCT	WEIGHT GT 75 PCT	75-20 PCT LT 75	20-5	5-2	LT .074	20-2 PCT LT20	BULK DENSITY 4A1D 1/3-BAR G/CC	4A1H OVEN DRY G/CC	4D1 COLE	WATER CONTENT 4B1C 1/10 BAR PCT	4B1C 1/3-BAR PCT	4B2 15-BAR PCT	4C1 WRD CM/CM	CARBONATE 6E1B LT 2 PCT	3A1A LT .002 PCT	PH 8C1A 1/1 H2O	8C1E 1/2 CACL
000-001	0	0	0	0	0		0						10.3		6		7.3	7.1
001-002	TR	0	0	0	TR		TR						4.2		8		8.0	7.5
002-005	1	0	0	1	TR		1	1.3 A					3.3		9		8.1	7.5
005-010	2	0	0	2	1		3	1.4 A					2.9		12		8.3	7.6
010-050	1	0	0	TR	1		1	1.6 A	1.70	.071		9.6	3.5	.08	15		8.3	7.3
050-100	5	0	TR	3	5		8	1.5 A					3.3		15		8.5	7.7
100-200	2	0	0	1	3		4	1.65	1.67	.004		10.5	3.6	.11	16		8.4	7.7
100-200																		
100-200								1.28	1.38	.025								

DEPTH CM	ORGANIC MATTER 6A1A ORGN CARB PCT	6B1A NITG PCT	C/N	IRON 6C2B EXT FE PCT	PHOS TOTL PCT	EXTRACTABLE BASES 5B4A 6N2E CA (MEQ / 100 G)	6O2D MG	6P2B NA	6Q2B K	SUM EXTB	ACTY 6H1A BACL TEA	AL 6G1E KCL EXT	CAT EXCH 5A3A EXTB ACTY	5A6A NHAC	RATIO 8D1 NHAC TO CLAY	RATIO 8D3 CA TO MG	CA 5F1 SAT NHAC PCT	BASE SAT 5C3 EXTB ACTY PCT	5C1 NHAC PCT
000-001	2.24	.178	13				2.7	TR	1.3					6.7	1.10				
001-002	.83	.081	10				2.5	TR	.4					4.4	.75				
002-005	.80	.055	15				2.9	TR	.3					4.2	.85				
005-010	.30	.023	13				3.8	TR	.1					3.1	.38				
010-050	.16	.018	9				4.7	.0	.1					3.4	.37				
050-100	.11	.018	6				4.6	.0	.1					2.7	.37				
100-200	.13	.018	7				5.4	TR	TR					3.0	.46				
100-200	.24	.021	11																
100-200																			

DEPTH CM	SATURATED PASTE 8F1 REST OHM-CM	8C1B PH	8A H2O PCT	NA 5D2 ESP PCT	NA 5E SAR	SALT 8D5 TOTL SOLU PPM	GYP 6F1A PCT	SATURATION EXTRACT 8A1 8A1A EC MMHOS/CM	6N1B CA (MEQ / LITER)	6O1B MG	6P1B NA	6Q1B K	6I1A CO3	6J1A HCO3	6K1C CL	6L1C SO4	6M1C NO3	ATTERBERG 4F1 LQID LMIT PCT	4F2 PLST INDX
000-001		6.4	58.7			2000	0	3.34	33.7	10.6	.1	9.8	.0	1.5	4.1	2.5	.0		
001-002		7.3	38.3			450		1.50	12.6	3.9	.1	1.7	.0	13.0	1.1	.6	.0		
002-005		7.3	32.5			330		1.26	10.5	4.2	.1	1.1	.0	9.5	.7	1.0	.0		
005-010		7.6	26.8			130		.69	4.8	2.2	.1	.6	.0	4.7	.4	.6	.0		
010-050								.208											
050-100	7200	8.3						.208											
100-200	3000	8.1	29.9		1	290		1.30	4.2	9.3	1.3	.3	.0	1.1	.6	14.5	.0	21	3 C
100-200																			
100-200																			

(A) ESTIMATE
(B) 1:2 SIOL WATER RATIO
(C) BY SOIL MECHANICS LABORATORY, USDA, LINCOLN, NE.

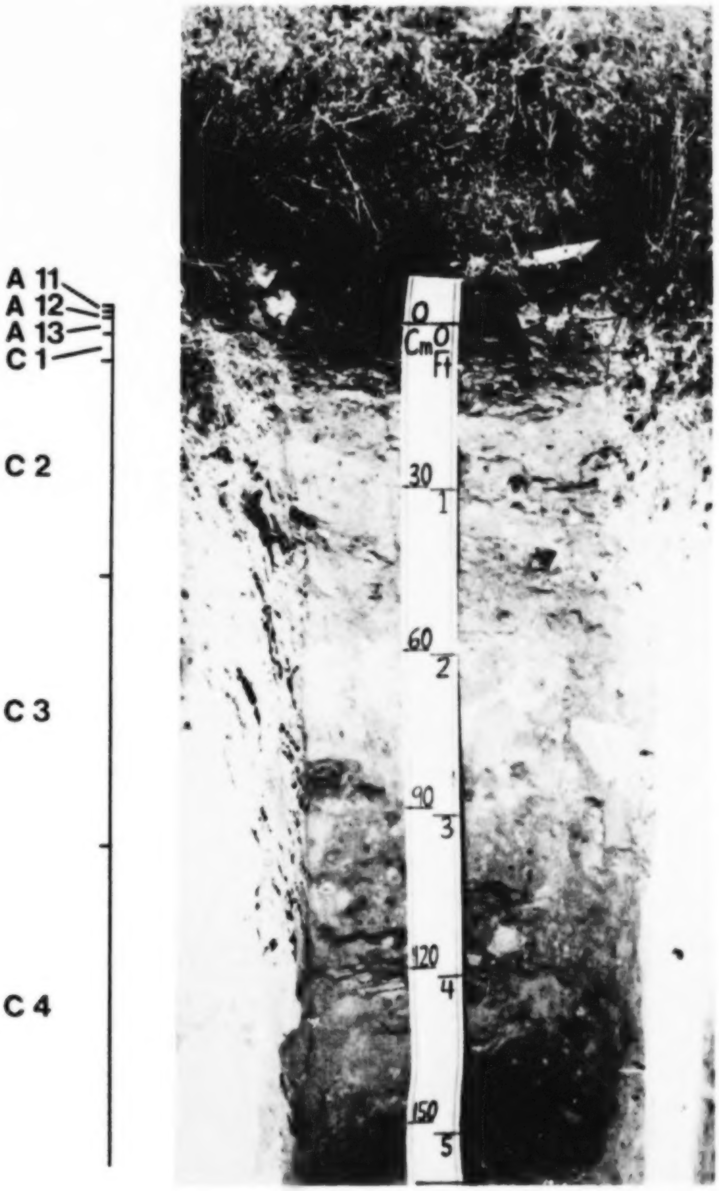
A 11
A 12
A 13
C 1
C 2
C 3
C 4
0
Cm
0
Ft
30
1
60
2
90
3
120
4
150
5

Fig. A-15. Photograph of 1970-15 soil profile.

APPENDIX B

Water Movement

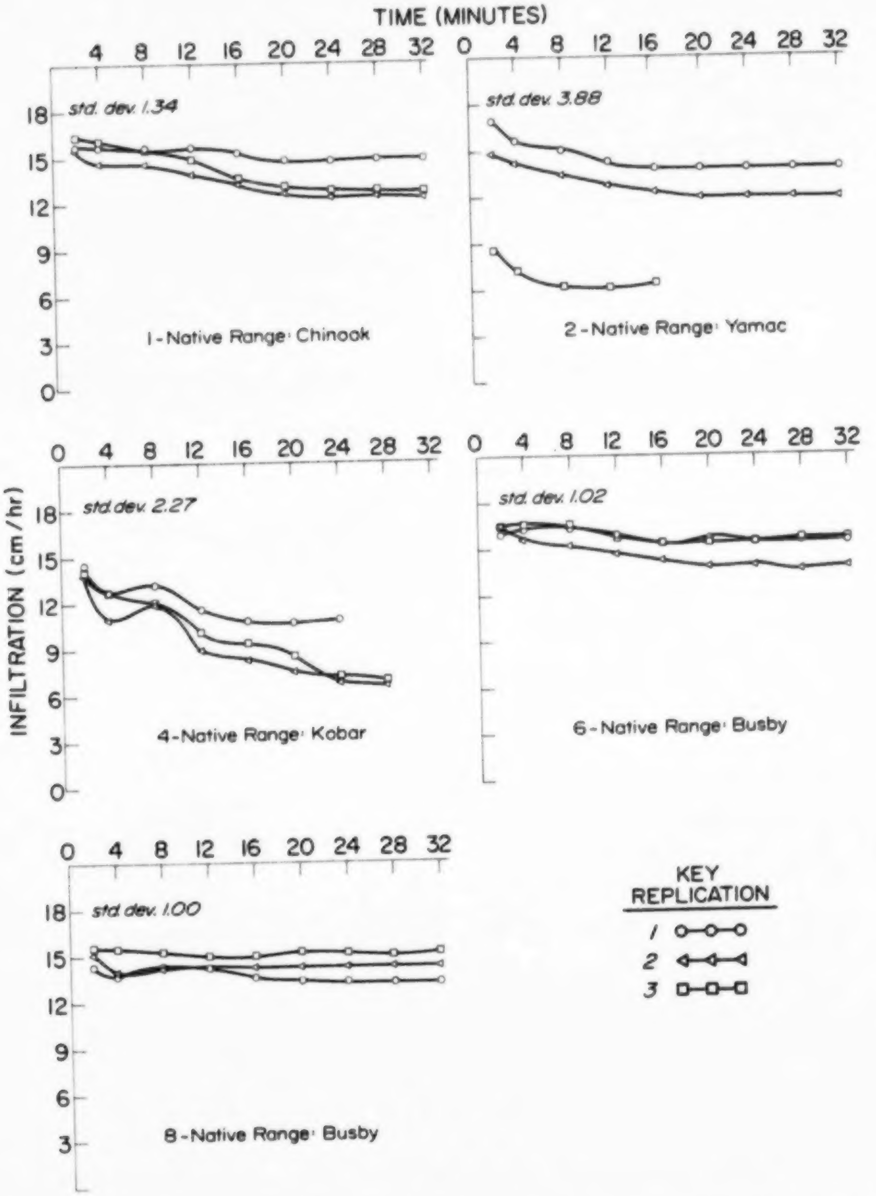

Fig. B-1. Infiltration vs. time measured in undisturbed soils at the Colstrip study area in August, 1976.

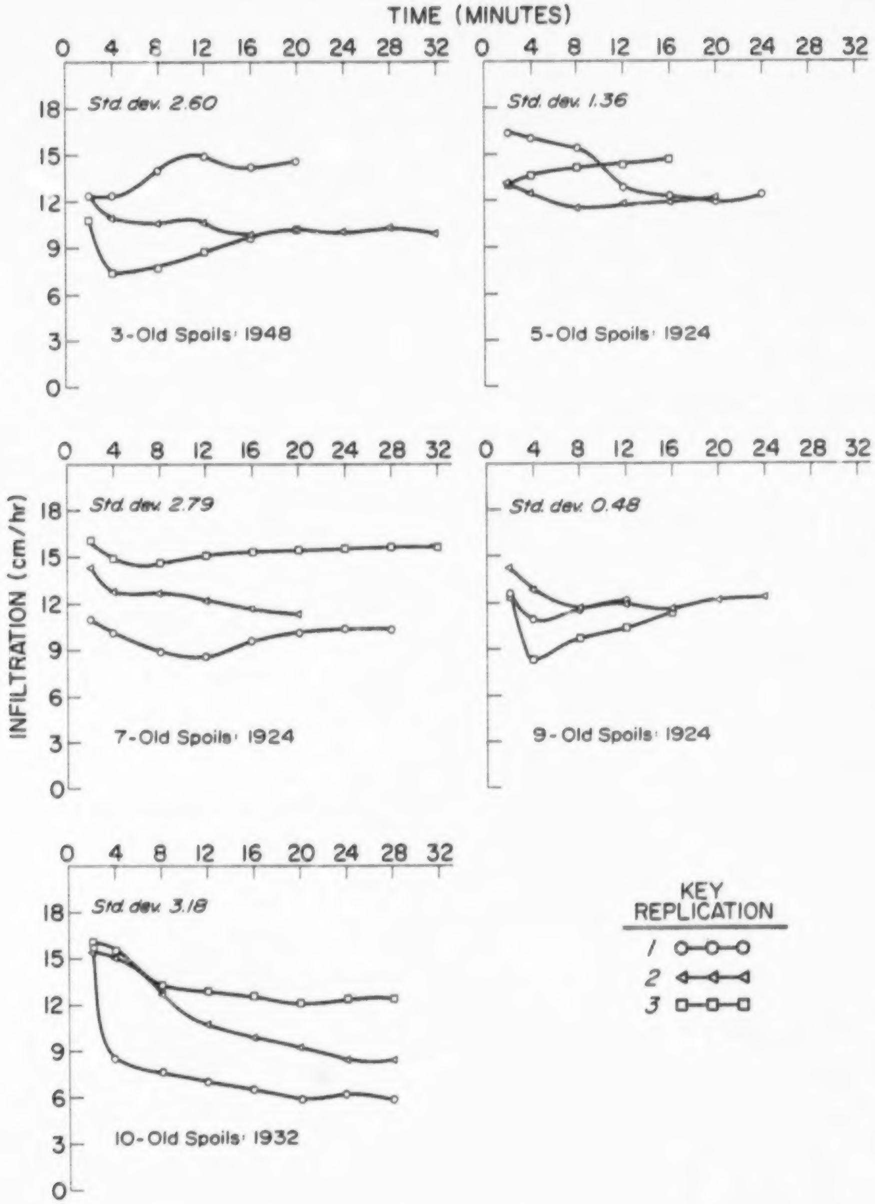

Fig. B-2. Infiltration vs. time measured in old spoils at the Colstrip study area in August, 1976.

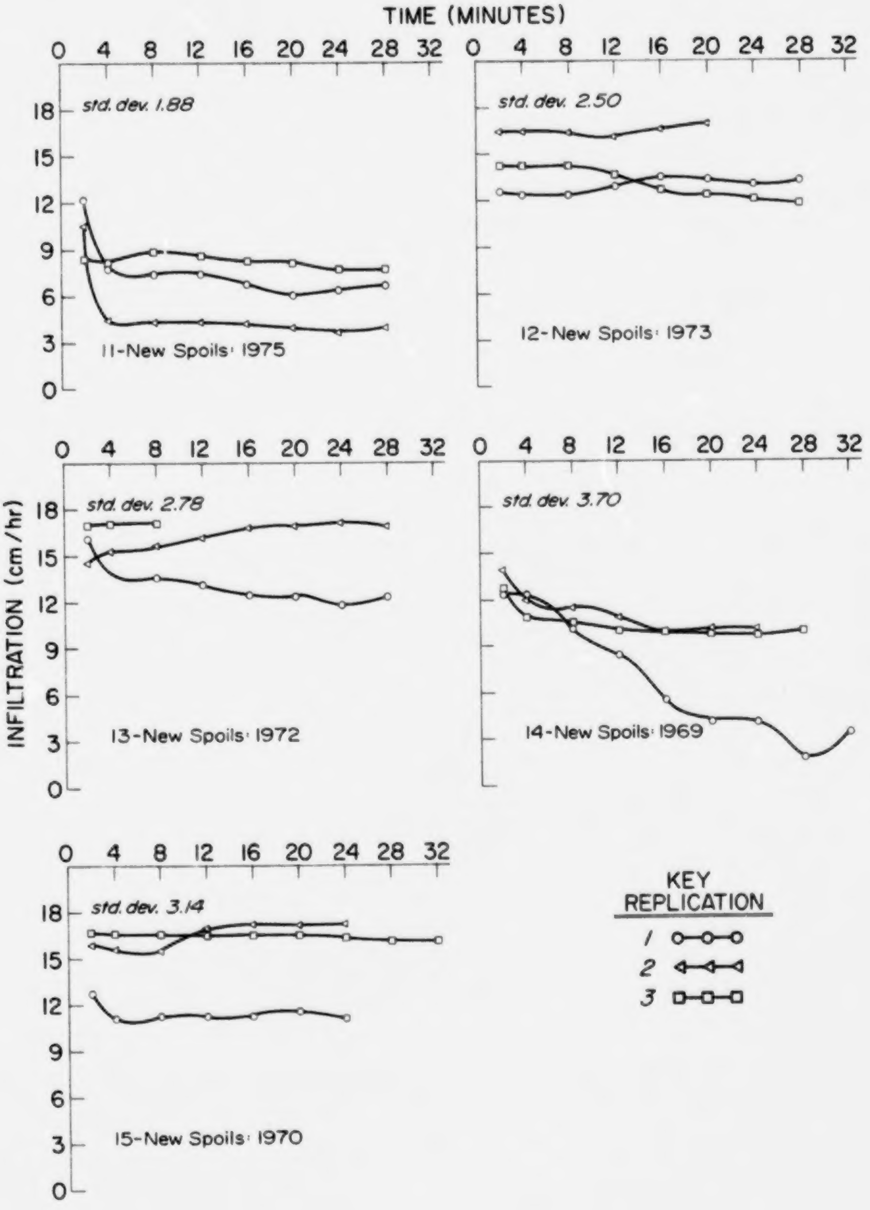

Fig. B-3. Infiltration vs. time measured in new spoils at the Colstrip study area in August, 1976.

Table B-1. Volumetric soil water content (%) at selected depths in natural soils near Colstrip, Montana.

Native soil	Depth (cm)	1976								1977											
		6/9	6/29	7/11	8/11	8/24	9/15	10/22	11/24	1/15	2/12	3/13	4/6	4/14	5/2	5/15	5/29	6/15	7/8	7/19	7/31
Chinook-1	15	21	18	10	05	09	06	10	13	25	32	23	31	20	09	15	22	14	07	06	04
	30	26	25	17	10	12	10	09	14	18	26	27	34	25	17	20	24	19	11	10	05
	45	26	27	21	12	13	11	10	13	14	18	26	34	28	23	24	24	20	13	12	11
	60	27	28	25	14	15	14	12	14	14	16	27	34	29	26	25	25	23	15	13	13
	75	28	29	27	16	18	16	15	17	15	18	27	32	31	27	27	26	25	18	17	15
	90	30	31	29	20	23	19	18	20	19	20	27	30	31	29	28	27	27	21	20	19
	120	28	30	29	24	29	24	22	24	21	22	25	26	31	28	31	27	27	25	24	23
	150	33	34	34	30	32	32	27	31	27	27	29	30	31	31	29	31	31	30	28	29
	180	30	31	32	28	31	29	26	29	25	26	26	27	30	28	30	28	28	27	26	27
	210	31	32	31	29	29	32	26	30	26	27	27	28	28	29	28	30	30	29	29	30
	240	29	30	30	28	31	28	25	30	26	27	27	27	25	28	27	29	29	28	28	28
Boxwell-2	15	33	38	27	26	18	18	25	30			37	41	37	19	34	31	27	18	17	16
	30	37	42	36	26	24	24	23	30			38	41	33	32	35	35	31	24	21	21
	45	38	41	37	29	26	26	25	28			37	40	39	34	35	35	33	26	24	24
	60	39	42	38	33	30	30	29	32			36	40	39	35	37	36	36	29	26	27
	75	40	42	39	37	35	35	34	38			37	42	40	35	39	37	38	33	32	33
	90	41	43	40	40	36	39	36	41			37	42	41	36	39	38	39	37	35	37
	120	40	42	39	40	37	39	38	41			36	41	40	35	36	38	38	39	38	39
	150	38	41	38	38	36	38	32	38			33	37	38	34	36	36	36	37	34	37
	180	38	40	37	37	35	36	31	37			32	33	36	33	34	35	36	35	34	36
	210	36	39	36	37	36	35	30	36			31	32	34	32	32	34	34	34	33	34
Ethridge-4	15			29	23	20	22	23	26		48	38	42	39	23	32	31	31	25	21	20
	30			35	27	25	26	22	27		46	38	42	40	36	34	35	31	26	24	26
	45			36	28	26	26	22	26		44	36	42	40	38	36	35	32	26	24	26
	60			38	30	26	26	21	26		43	34	42	39	38	36	36	33	28	26	28
	75			37	29	25	25	21	25		38	30	38	37	38	33	35	32	29	26	29
	90			34	29	26	25	20	25		33	27	30	32	34	31	32	30	29	27	29
	120			28	27	25	25	21	24		29	22	24	25	25	23	25	24	25	24	24
	150			27	27	25	25	21	25		28	22	23	22	23	21	23	23	22	22	23
	180			25	26	24	25	22	25		28	22	23	23	21	28	21	21	23	23	23
	210			31	31	29	30	27	30		34	27	28	27	26	31	27	27	28	28	27
Riedel-6	15	13	16	10	03	05	04	11	12	21	29	19	28	21	14	11	14	14			
	30	19	23	16	07	07	09	09	15	19	24	21	31	24	19	20	20	14			
	45	29	21	19	11	10	07	09	15	16	17	19	30	25	23	17	20	16			
	60	21	20	21	15	14	10	12	13	16	17	17	28	25	23	20	19	18			
	75	24	22	23	18	18	14	19	15	18	18	18	28	26	26	21	20	26			
	90	27	23	24	20	19	17	17	18	19	19	19	25	26	28	22	22	28			
	120	27	24	27	23	22	19	17	18	21	21	20	21	25	28	24	22	23			
	150	30	26	29	25	25	22	21	21	22	23	22	22	25	29	25	24	25			
	180	33	29	32	27	28	24	22	23	25	25	28	23	25	30	27	25	26			
	210	40	36	40	34	34	26	25	24	28	30	27	27	28	33	31	28	31			
	240		37	36	34	33	33	31	30												
Chinook-8	15	17	15	07	04	03	03	06	11	14	32	17	23	17	-4	10	14	08	06	04	03
	30	21	21	14	09	08	07	06	11	11	27	19	26	20	13	15	18	14	09	07	06
	45	24	23	19	12	11	09	08	11	10	25	20	29	23	18	19	21	17	11	10	09
	60	27	26	22	14	13	11	09	13	11	22	20	31	26	22	21	23	19	13	11	10
	75	26	25	22	15	13	12	08	13	11	17	17	27	25	23	19	21	19	15	13	19
	90	26	23	22	15	14	12	10	13	11	17	14	21	23	21	23	19	17	15	13	12
	120	30	30	30	26	23	19	16	20	18	20	21	21	24	24	22	23	22	19	17	15
	150	28	28	29	25	23	20	15	20	19	20	19	20	20	21	18	22	21	22	20	21
	180	25	25	25	28	21	19	13	19	17	19	17	17	18	18	27	18	18	19	19	19
	210	25	25	25	23	22	19	15	20	17	17	17	18	18	17	16	17	16	27	16	18
	240	23	23	23	22	21	19	14	19	16	18	17	24	17	17	16	17	16	17	17	16

Table B-2. Volumetric soil water content (%) at selected depths in old minesoils near Colstrip, Montana.

Old spoil	Depth (cm)	1976 6/9	6/29	7/11	8/11	8/24	9/15	10/22	11/24	1977 1/11	2/12	3/13	4/6	4/14	5/2	5/15	5/29	6/15	7/8	7/19	7/31
	15	21	20	15	07	07	07	12	16	27	36	25	20	27	10	19	19	27			
	30	23	26	20	13	12	12	10	16	18	24	24	31	28	24	20	26	23			
	45	22	24	20	12	11	11	09	12	12	15	19	29	27	25	19	24	21			
	60	22	23	20	12	11	10	08	11	10	12	12	24	25	23	81	22	18			
1928-5	75	22	21	19	11	10	10	10	10	09	10	09	17	21	22	17	19	15			
	90	23	21	20	11	10	10	08	10	10	11	09	14	15	19	14	17	13			
	120	27	25	24	14	13	13	10	13	12	13	11	11	12	14	10	14	13			
	150	22	21	20	11	10	10	07	10	10	11	09	10	09	10	07	10	10			
	180	11	12	12	09	08	08	06	08	08	09	07	08	08	08	07	08	08			
	210	08	09	09	09	08	08	06	08	08	09	07	08	08	08	07	07	07			
	15	14	10	06	05	04	08	12	13	20	32	23	31	26	13	16	19	17			
	30	23	19	10	11	10	10	13	16	16	23	23	32	28	28	18	25	18			
	45	24	20	14	12	11	10	12	12	12	15	19	30	27	32	19	24	19			
	60	24	21	15	12	12	09	12	12	11	12	15	24	24	31	17	23	19			
1928-7	75	23	20	14	11	10	08	10	11	09	10	10	15	17	27	12	20	16			
	90	21	18	14	10	09	08	08	09	08	09	08	10	12	19	11	14	13			
	120	21	20	14	11	11	10	10	11	09	11	09	10	10	14	10	11	11			
	150	21	20	15	14	13	11	12	13	12	13	12	12	12	15	11	11	12			
	180	19	19	18	15	14	13	14	15	13	14	12	13	13	16	11	13	13			
	210	17	17	18	16	15	13	14	15	14	15	13	14	13	16	12	13	13			
	240	16	16	17	16	16	14	15	16	14	15	14	14	14	14	12	14	13			
	15	16	18	10	07	06	00	09	15	20	26	22	28	23	09	14	10	13			
	30	20	23	17	13	11	11	10	15	17	17	22	29	25	19	21	18	13			
	45	20	23	19	14	11	11	10	12	14	14	20	28	24	21	18	22	17			
	60	20	22	11	14	11	11	07	11	12	14	17	26	29	21	19	22	17			
1928-9	75	21	23	20	15	12	12	07	12	12	13	15	23	23	21	19	21	18			
	90	22	23	21	16	13	12	10	12	12	12	15	20	21	21	20	21	18			
	120	23	24	23	19	15	14	10	14	13	13	14	19	18	18	19	20	18			
	150	24	24	24	21	17	16	10	16	15	15	15	17	19	19	18	19	18			
	180	24	24	24	23	19	18	12	18	17	17	16	16	18	20	17	18	18			
	15	28	33	20	09	08	07	12	18	23	38	28	39	33	18	24	24	19	12	08	08
	30	30	50	26	15	13	11	11	17	20	31	28	39	35	30	26	30	22	17	13	13
	45	29	35	27	17	16	14	12	16	16	25	24	36	32	30	24	29	23	18	16	15
	60	28	32	25	18	17	15	10	16	14	23	20	29	29	27	22	25	22	18	16	16
1929-1[illegible]	75	26	29	24	18	17	15	13	15	14	21	17	20	23	23	20	22	20	18	16	16
	90	27	29	25	21	20	17	16	18	15	23	18	19	20	21	20	21	20	18	16	17
	120	27	30	26	24	23	20	17	21	18	22	20	20	20	20	18	20	20	20	19	19
	150	24	26	24	24	24	21	19	22	18	22	19	20	19	18	18	18	19	19	18	18
	180	21	23	21	22	22	20	16	21	18	21	19	19	19	12	18	19	19	19	18	18
	210	21	22	20	22	21	20	17	21	18	23	19	20	19	19	17	19	19	19	18	18
	240	19	20	19	20	20	19	16	20	17	12	18	19	18	19	18					
	15			31	21	22	20	28	30	38	49	44	49	45	27	37	32	31	26	24	20
	30			42	37	37	33	35	37	39	52	48	53	51	42	45	42	41	35	33	32
	45			40	48	46	43	45	46	41	57	50	59	56	49	54	46	45	42	39	40
	60			52	52	50	47	41	50	48	56	42	56	57	57	48	52	49	47	45	48
1948-3	75			46	44	43	40	38	43	41	51	46	47	49	50	47	46	43	41	39	41
	90			48	49	47	44	45	48	46	54	48	50	50	49	53	46	47	44	41	42
	120			53	55	54	49	44	53	50	56	52	53	56	55	51	53	50	49	48	49
	150			54	55	53	50	49	53	45	55	51	54	54	53	52	51	52	50	47	47
	180			48	57	55	51	52	53	49	60	52	56	54	53	61	52	52	48	46	48
	210			49	63	63	57	51	63	59	63	59	59	61	61	48	60	61	59	57	59
	240			40	52	51	47	45	49	47	49	47	47	58	49	51	48	49	47	46	46

Table B-3. Volumetric soil water content (%) at selected depths in new minesoils near Colstrip, Montana.

New Spoil	Depth (cm)	1976 6/9	6/29	7/11	8/11	8/24	9/15	10/22	11/24	1977 1/15	2/12	3/13	4/6	4/14	5/2	5/15	5/29	6/15	7/8	7/19	7/31
	15	27	36	23	17	17	17	18	22	26	42	31	38	32	21	28	26	25	18	15	14
	30	33	41	30	23	23	22	21	23	25	41	33	39	35	29	30	29	28	24	22	20
	45	35	44	34	27	25	25	22	24	24	37	33	38	36	33	31	33	30	26	23	23
	60	35	45	34	28	26	26	23	23	24	38	32	36	37	34	33	32	30	26	25	24
1969	75	39	48	39	36	35	32	34	29	31	44	27	41	41	36	36	33	37	32	29	27
	90	44	52	42	40	37	38	27	35	33	45	38	36	41	43	26	42	38	28	37	37
	120	31	37	31	29	28	25	26	22	22	34	26	26	27	26	22	26	26	24	22	21
	150	28	31	27	25	24	22	18	22	19	28	21	21	22	22	25	22	21	20	19	19
	180	30	32	27	27	26	24	19	21	21	31	23	23	24	24	24	25	24	25	23	23
	210	29	34	29	29	29	28	26	24	23	31	26	26	26	25	27	23	25	24	24	23
	15	15	17	08	03	02	04	10	10	22	37	21	30	20	40	12	09	10	06	03	00
	30	22	28	18	11	09	09	10	14	18	27	26	33	27	18	18	20	15	10	08	07
	45	24	28	23	15	13	12	12	14	14	20	24	30	27	23	21	22	17	13	11	10
	60	26	29	26	19	16	16	13	14	14	20	22	27	28	25	23	22	19	16	14	13
1970	75	28	29	28	21	18	16	14	14	14	22	21	25	28	26	25	23	21	17	16	14
	90	29	32	31	24	19	18	15	16	16	23	20	23	28	27	24	24	22	19	17	15
	120	31	32	32	25	21	20	17	17	17	21	19	20	24	25	21	23	22	20	18	16
	150	30	31	31	26	22	19	18	18	18	19	18	19	21	21	18	21	21	19	18	17
	180	27	27	28	24	21	18	16	17	16	17	17	17	18	18	18	18	18	17	16	16
	210	25	26	26	25	21	20	16	17	16	18	17	18	18	18	18	18	19	18	16	16
	15		04	00	00	00	00	08	04	19	23	12	19	25	01	09	01	00	00	00	01
	30		21	10	06	06	07	10	15	23	32	20	30	29	11	19	15	08	07	04	00
	45		28	20	11	10	12	12	17	20	28	25	36	33	22	24	21	12	10	09	08
	60		31	25	11	16	17	17	19	22	27	26	34	34	19	27	24	17	15	12	12
1972	75		33	30	22	21	23	18	22	24	26	29	33	34	31	25	28	22	21	18	16
	90		32	30	23	22	23	20	22	22	24	28	31	33	30	30	27	21	24	21	19
	120		32	31	26	25	26	20	24	24	25	28	[illegible]	31	31	29	28	25	26	24	22
	150		31	30	26	24	26	20	24	24	25	27	25	26	29	27	27	25	25	23	24
	180		29	28	25	24	25	20	22	23	23	24	24	24	26	26	25	24	24	22	28
	210		28	28	26	25	26	19	23	23	23	23	25	25	26	26	25	24	27	25	25
	240		28	28	27	26	28	22	24	23	24	24	25	25	24	27	24	23	24	23	22
	15		23	14	08	07	09	17	15	22	28	23	30	23	09	17	14	09	08	07	05
	30		34	27	16	14	16	16	20	22	26	26	[illegible]	29	22	22	24	18	17	16	15
	45		37	31	20	18	19	18	20	21	23	25	32	30	26	24	25	20	19	17	16
	60		37	33	23	20	22	20	20	24	25	24	28	31	29	28	26	24	21	20	20
1973	75		38	35	27	24	25	24	23	26	27	26	27	31	27	26	29	27	23	22	22
	90		39	37	31	28	29	24	26	24	27	24	26	29	28	32	26	25	23	23	23
	120		38	37	31	28	29	27	24	30	31	29	[illegible]	31	33	30	32	31	32	32	33
	150		40	37	35	32	33	29	30												
	15		27	22	19	19	17	26		30	41	27	40	28	15	25	18	20	19	14	13
	30		36	32	28	29	27	26		28	39	31	39	33	30	29	31	27	26	23	23
	45		37	35	31	32	30	28		29	37	31	38	35	32	29	33	29	28	25	25
	60		38	35	33	34	32	30		30	35	31	37	35	34	33	33	31	31	28	28
1975	75		38	37	34	36	34	31		31	36	33	36	35	35	33	34	32	33	30	31
	90		38	36	35	37	35	31		33	37	33	35	35	35	33	35	33	34	32	32
	120		39	37	36	39	37	34		34	38	33	35	34	35	34	34	33	35	34	34
	150		39	38	37	40	38	34		34	39	33	35	34	34	34	35	34	37	34	36

Table B-4. Soil temperatures (°C) for undisturbed soils and minespoils at Colstrip study area.

Site	Depth (cm)	DATE															
		1976							1977								
		6/29	7/11	8/11	8/24	9/15	10/22	11/24	2/12	3/13*	5/2	5/10	5/31	6/15	7/9	7/19	7/31
CHINOOK-1	15	14.9	21.7	22.2	23.4	14.7	6.8	1.1		6.9	14.4	20.7	18.6	18.6	20.5	27.6	24.6
	50	15.9	19.0	23.7	25.1	17.8	5.7	2.3		3.2	13.0	14.2	15.2	19.5	22.0	23.2	21.2
	90	13.7	15.9	21.5	22.0	18.6	11.3	5.9		4.1	10.8	11.3	13.9	16.4	19.5	16.6	19.0
	150	12.0	11.5	18.6	19.5	17.8	13.9	9.1		5.1	8.1	8.6	11.5	13.0	15.9	15.2	15.9
YAMAC-2	15	13.9	19.8	21.2	22.7	16.4	8.4	3.0			13.5	19.5	18.1	24.1	24.6	27.6	22.0
	50	14.2	17.3	22.7	22.9	18.3	10.4	5.2			13.0	13.9	14.7	18.1	20.3	22.2	21.2
	90	13.7	15.4	21.2	21.7	18.6	12.5	6.9			10.8	11.3	13.7	16.1	18.3	19.8	19.3
	150	12.0	12.2	19.0	19.5	18.3	15.2	9.8			8.5	8.8	11.3	12.2	14.2	14.7	15.9
1948-3	15													19.3	21.2	24.9	22.7
	50													18.3	20.0	22.0	22.0
	90													14.9	16.4	17.3	18.8
	150													12.0	13.5	14.7	15.9
1924-5	15	14.7	21.2	24.1	24.4	16.4	5.0	5.0									
	50	13.9	20.0	24.1	24.4	17.6	7.9	3.5									
	90	13.5	19.8	23.2	22.7	17.8	10.4	4.5									
	150	12.0	13.7	20.3	20.0	17.6	14.4	8.4									
BUSBY-6	15	x	21.2	23.2	24.4	16.9	5.0	5.9									
	50	14.9	19.8	22.2	22.7	17.8	10.5	6.4									
	90	13.5	16.9	21.2	21.0	x	12.5	7.6									
	150	12.5	13.0	18.6	18.6	17.1	14.9	10.1									
1924-7	15	10.1	21.5	23.4	25.1	18.6	5.4	4.0			14.7	20.3	13.5	17.3			
	50	13.1	20.0	23.4	24.1	18.8	9.9	4.7			14.7	15.9	15.9	19.3			
	90	12.7	18.6	22.7	23.2	18.8	11.4	5.7			12.5	13.5	x	19.0			
	150	10.8	11.3	18.8	20.0	18.6	15.4	10.1			9.1	10.1	12.7	14.7			
BUSBY-8	15	15.2	22.7	x	x	x	x	1.1			14.9	20.7	13.9	20.5	22.7	31.9	22.7
	50	14.9	21.7	24.9	24.9	20.1	10.1	5.0			14.9	x	15.6	19.0	23.2	23.9	22.9
	90	13.7	18.6	22.9	22.7	20.0	12.5	6.9			12.5	13.5	12.7	16.9	17.8	16.9	18.1
	150	12.0	14.7	20.3	20.3	19.5	15.4	9.8			9.6	10.5	x	15.4	17.3	16.9	5.7
1924-9	15	14.4	22.0	25.1	25.1	18.8	5.4	3.5	1.1	21.5							
	50	14.9	21.2	25.1	24.6	18.1	9.1	3.7	1.3	4.6							
	90	13.9	18.8	x	23.2	18.6	11.4	5.2	1.8	4.7							
	150	11.3	11.5	20.3	20.3	18.1	15.0	9.1	3.7	5.2							
1932-10	15	12.2	23.2	21.5	22.7	19.0	5.4	1.3			13.5	19.3	17.6	18.1	13.5	26.3	22.2
	50	13.5	19.5	23.4	26.1	18.1	9.1	3.3			13.7	14.7	14.7	20.1	x	24.6	23.4
	90	12.7	17.3	22.2	22.7	18.6	11.0	5.0			11.3	11.5	13.7	17.3	22.0	21.0	21.2
	150	12.0	13.9	19.5	20.3	18.6	14.4	8.1			13.2	8.8	11.4	13.9	19.5	x	x
1975-11	15	15.4	20.7	22.7	23.2	16.9	6.2	1.8			13.5	15.9	15.9	24.6	21.3	26.1	21.7
	50	12.7	20.3	23.7	24.8	19.3	9.4	2.5			13.9	15.6	15.4	18.3	22.4	23.7	22.4
	90	12.0	17.8	22.7	23.7	19.3	10.8	2.5			12.0	13.0	14.2	17.1	20.0	21.0	22.0
	150	11.0	13.9	20.3	21.0	19.0	13.9	1.1			9.1	9.8	12.0	14.2	17.1	15.6	17.6
1973-12	15	11.5	17.3	22.2	25.1	18.3	10.5	5.4	1.8		12.5	18.1	14.9	22.4	20.5	24.9	20.7
	50	15.4	17.8	21.5	22.4	15.9	5.7	5.2	1.3		12.0	13.5	13.7	17.1	21.0	22.0	21.2
	90	10.5	14.9	20.5	21.0	17.8	8.6	5.9	7.8		10.1	10.5	12.2	15.4	18.3	19.3	18.8
	150	9.3	11.5	18.3	18.8	17.6	13.2	8.4	6.2		7.9	8.6	11.0	13.0	15.4	15.9	16.6
1972-13	15	12.0	17.8	20.3	22.9	15.4	6.	4.7	1.6	4.2	12.2	18.8	17.3	22.4	22.2	22.4	21.2
	50	12.5	16.6	21.2	22.0	17.3	9.1	5.0	1.8	3.0	12.0	13.2	13.7	17.1	20.7	22.9	21.7
	90	11.8	15.4	20.5	21.5	17.3	10.1	5.4	2.5	3.3	10.1	10.5	12.2	15.6	18.1	19.8	19.3
	150	10.5	12.0	17.8	18.8	17.3	13.1	8.1	4.0	x	7.6	8.1	10.5	12.2	14.4	15.4	16.1
1969-14	15	13.0	19.3	22.0	20.7	15.4	4.0				13.0		18.1	16.9	22.7	24.9	21.7
	50	12.0	19.5	x	x	x					13.0		14.9	19.0	21.2	23.7	22.4
	90	12.5	19.0	21.7	21.5	x					11.8		14.6	17.8	19.8	21.7	21.5
	150	11.0	13.2	18.1	18.6	18.6					x		x	14.9	18.1	17.1	x
1970-15	15	12.7	20.7	22.2	22.0	16.4	5.7	4.0			13.9	16.4	17.8	4.0	13.9	16.4	17.8
	50	13.2	19.3	21.7	22.7	19.0	9.1	4.2			13.7	14.7	14.4	4.2	13.7	14.7	14.4
	90	12.7	16.6	20.5	21.2	19.0	10.8	5.2			11.5	12.0	13.9	5.2	11.5	12.0	13.9
	150	11.5	13.7	18.3	18.8	18.6	13.7	x			9.3	8.6	7.6	x	9.3	8.6	7.6

* - Psychrometers removed for cleaning and calibration
x - Denotes psychrometer failure

APPENDIX C

Root Activity

Derivation of the Plant Activity Index

Plant radioactivity is proportional to the amount of ^{32}P in the above ground portion of the plant

(1) Thus, $FC = K_1 (PQ)$

where FC = Field count
K_1 = Proportionality constant (geometry factory)
PQ = Radioactive quantity in plant tops

Decay of all radioactive substances is expressed by the equation

$$N = N_o e^{-\lambda t} \tag{2}$$

where N = Number of atoms remaining at time t
N_o = Original number of atoms present
$e^{-\lambda t}$ = Decay constant
λ = 0.693/half-life (14.3 days for ^{32}P)

Thus, the radioactive quantity of ^{32}P taken up by the plant tops from injected ^{32}P in the soil is the sum of ^{32}P accumulated (PA) during each time increment since P^{32} injection corrected for decay.

$$PQ = \sum_{t=1}^{t=2} (PA) e^{-\lambda t} \tag{3}$$

where $PA = K_2 (SQ)$
and K_2 = Proportion of total P^{32} taken up by roots and transported to plant tops during some time period.
SQ = Available P^{32} in the root zone.

Integrating from t_1 to t_2

$$PQ = \int_{t=1}^{t=2} (PA) e^{-\lambda} dt \tag{4}$$

(5) $$PQ = \frac{PA\,(e^{-\lambda t_2} - e^{-\lambda t_1})}{-\lambda}$$

Substituting (1) into (5) and rearranging

(6) $$K_1(PA) = \frac{FC\ (-\lambda)}{(e^{-\lambda t_2} - e^{-\lambda t_1})} = PAI$$

where PAI is defined at the plant activity index.

This equation can be extended to evaluate P^{32} uptake by a plant top between measurement dates by subtracting the residual radioactivity of P^{32} taken up during previous measurement periods. A modified field count (FC') can be defined as

(7) $$FC' = FC_2 - FC_1\,e^{-\lambda t}$$

where $t = t_2 - t_1$

FC' is the corrected field count at time t_2 suitable for substitution into (7). In this case, in (7) t_2 would be the time elapsed from injection to measurement date 2 and t_1 would be the elapsed time from injection to measurement date 1.

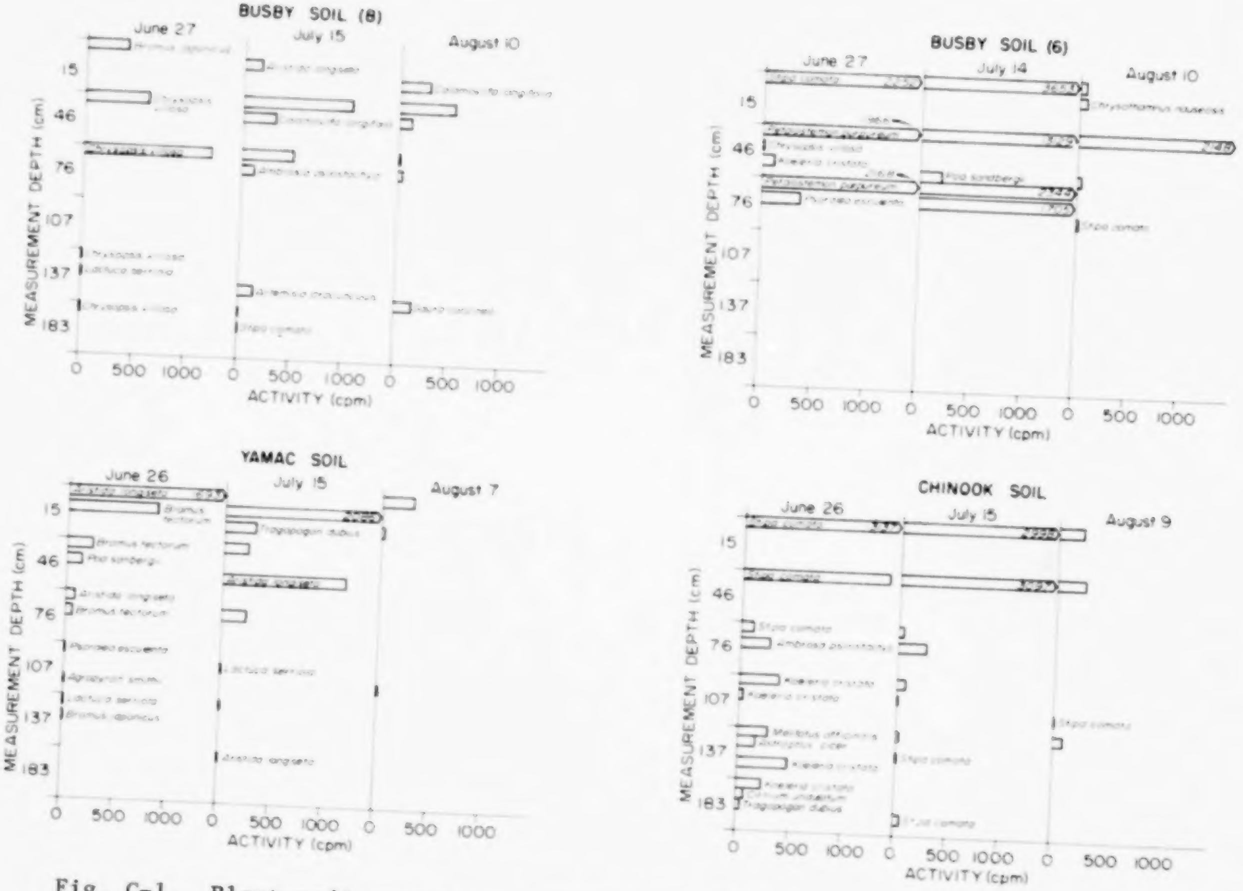

Fig. C-1. Plant radioactivities measured *in situ* on undisturbed soils at the Colstrip study area in 1976.

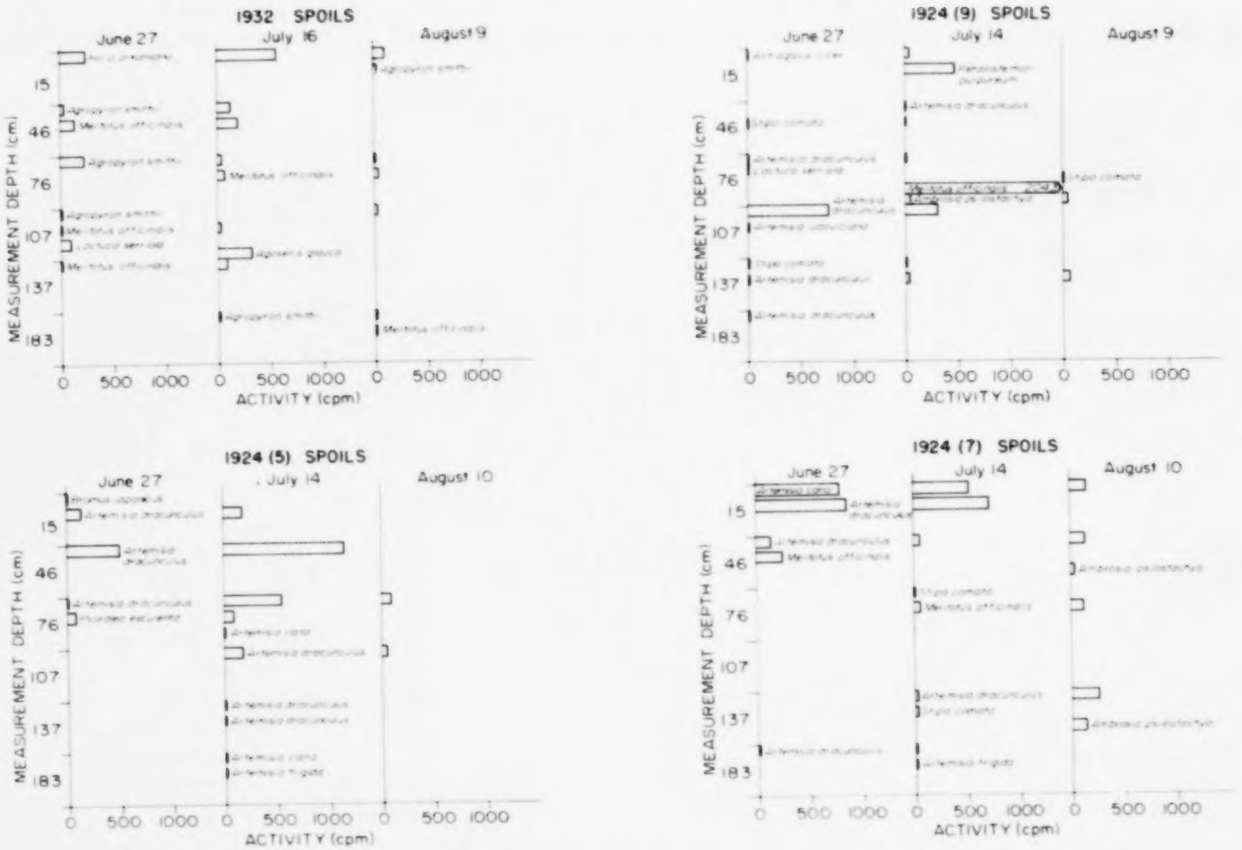

Fig. C-2. Plant radioactivities measured *in situ* on old spoils at the Colstrip study area in 1976.

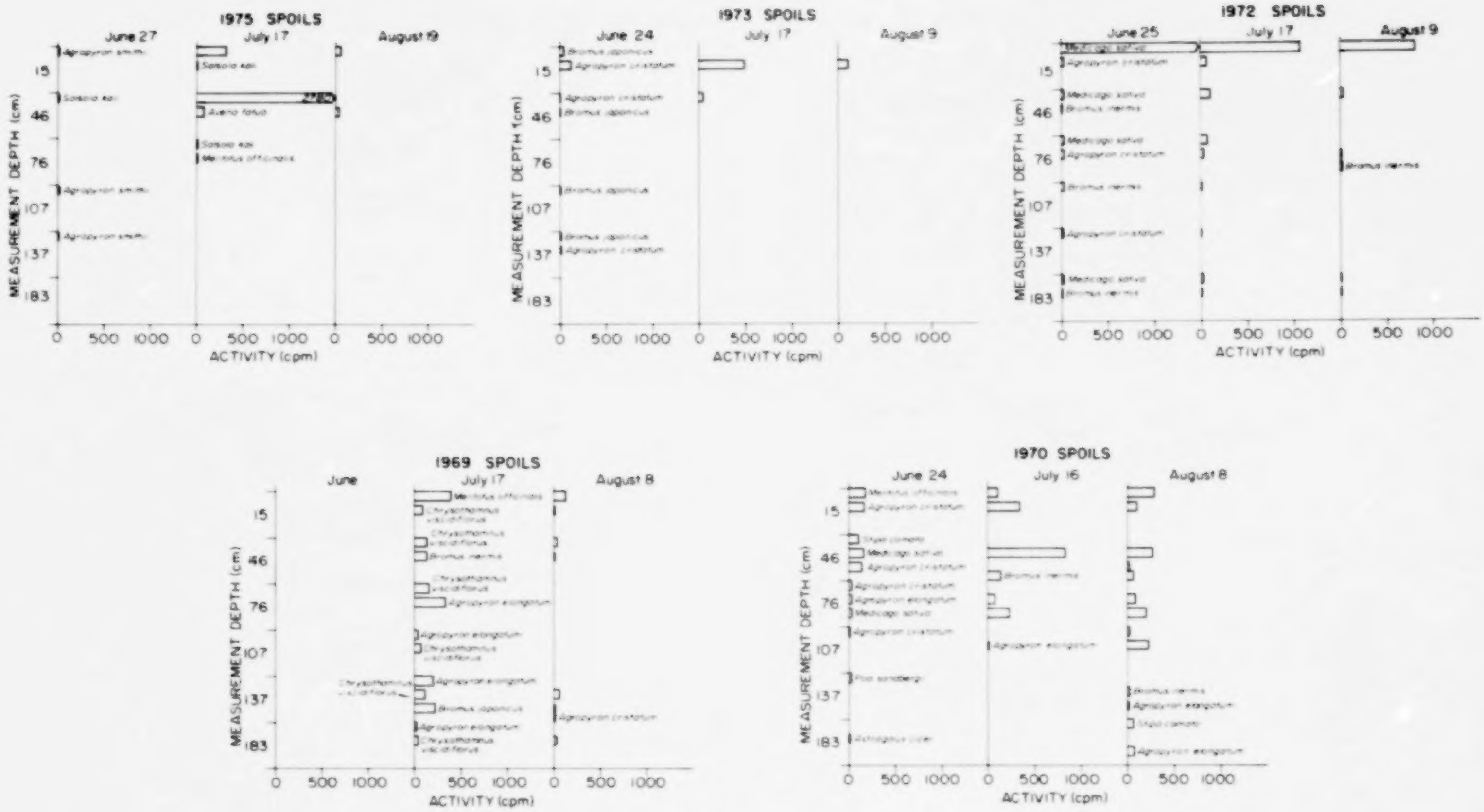

Fig. C-3. Plant radioactivities measured *in situ* on new mine spoils at the Colstrip study area in 1976.

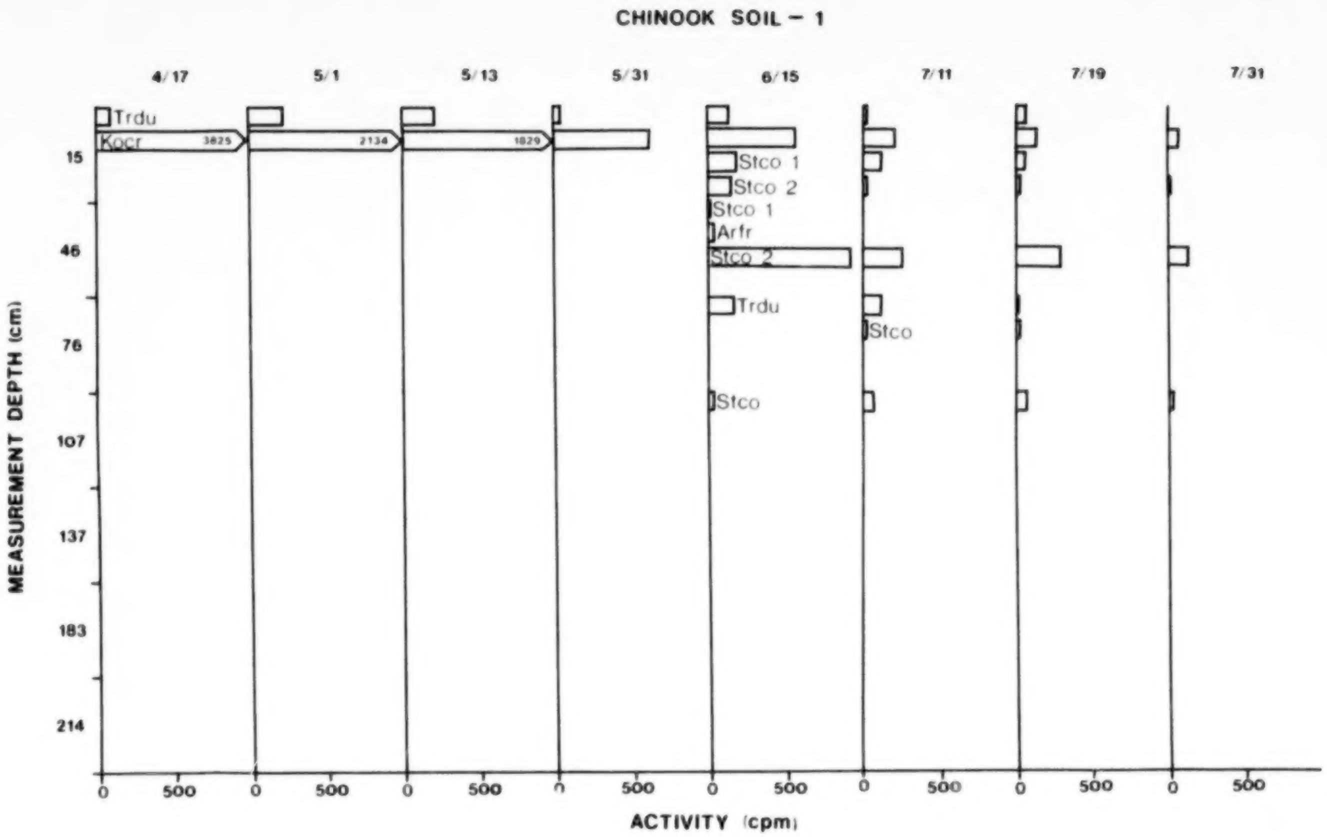

Fig. C-4. *In situ* plant radioactivities on Chinook-1 undisturbed soil at Colstrip study area - replication 1, 1977.

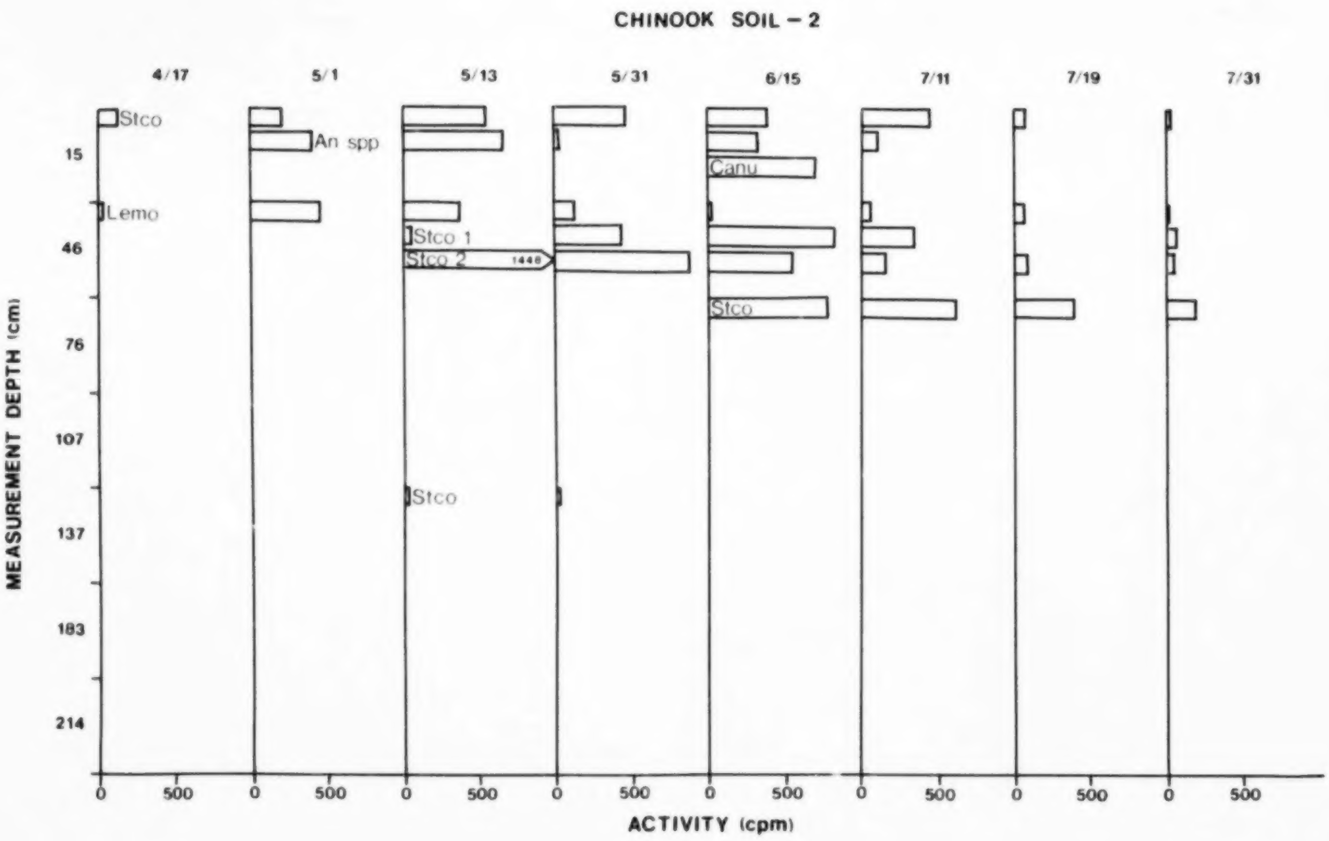

Fig. C-5. *In situ* plant radioactivities on Chinook-1 undisturbed soil at Colstrip study area - replication 2, 1977.

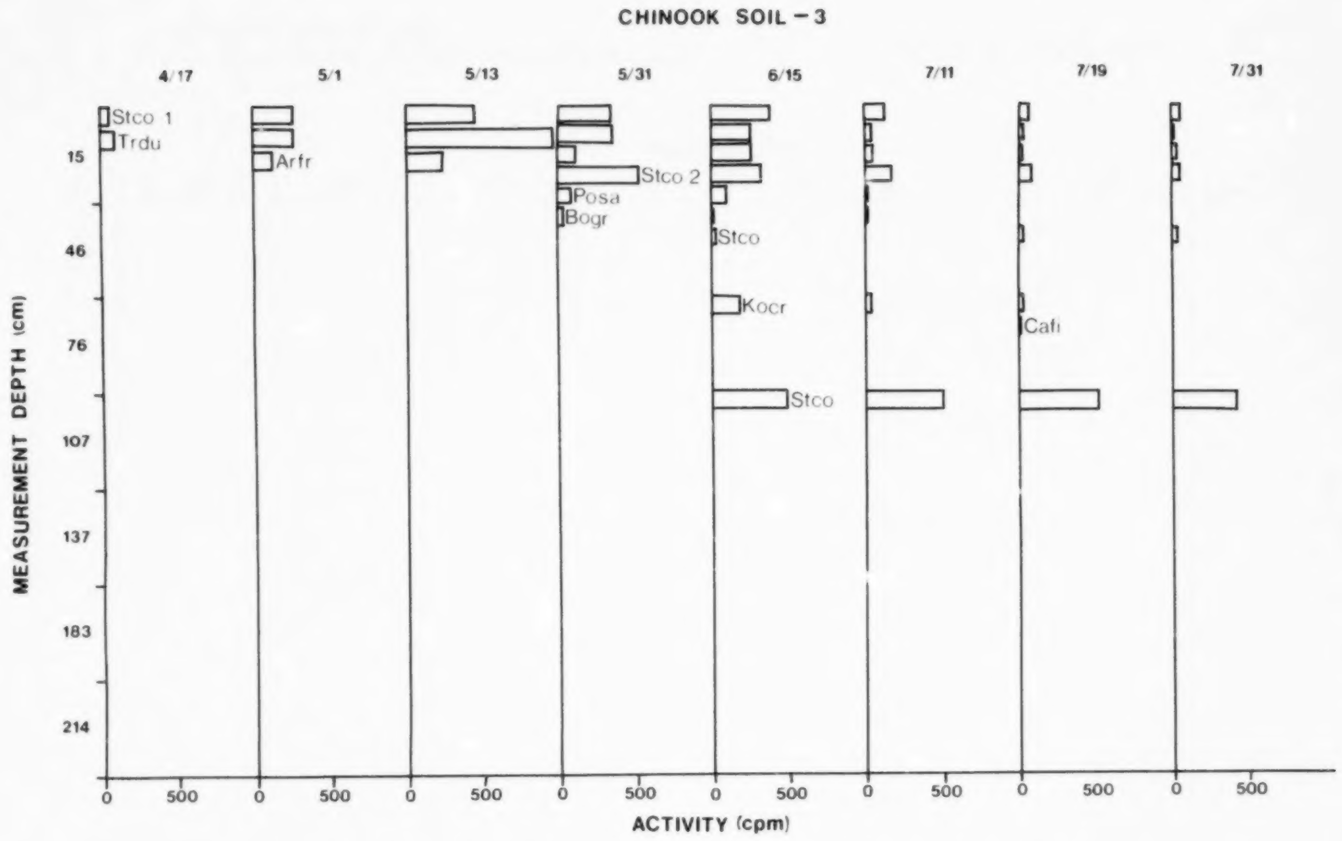

Fig. C-6. *In situ* plant radioactivities on Chinook-1 undisturbed soil at Colstrip study area - replication 3, 1977.

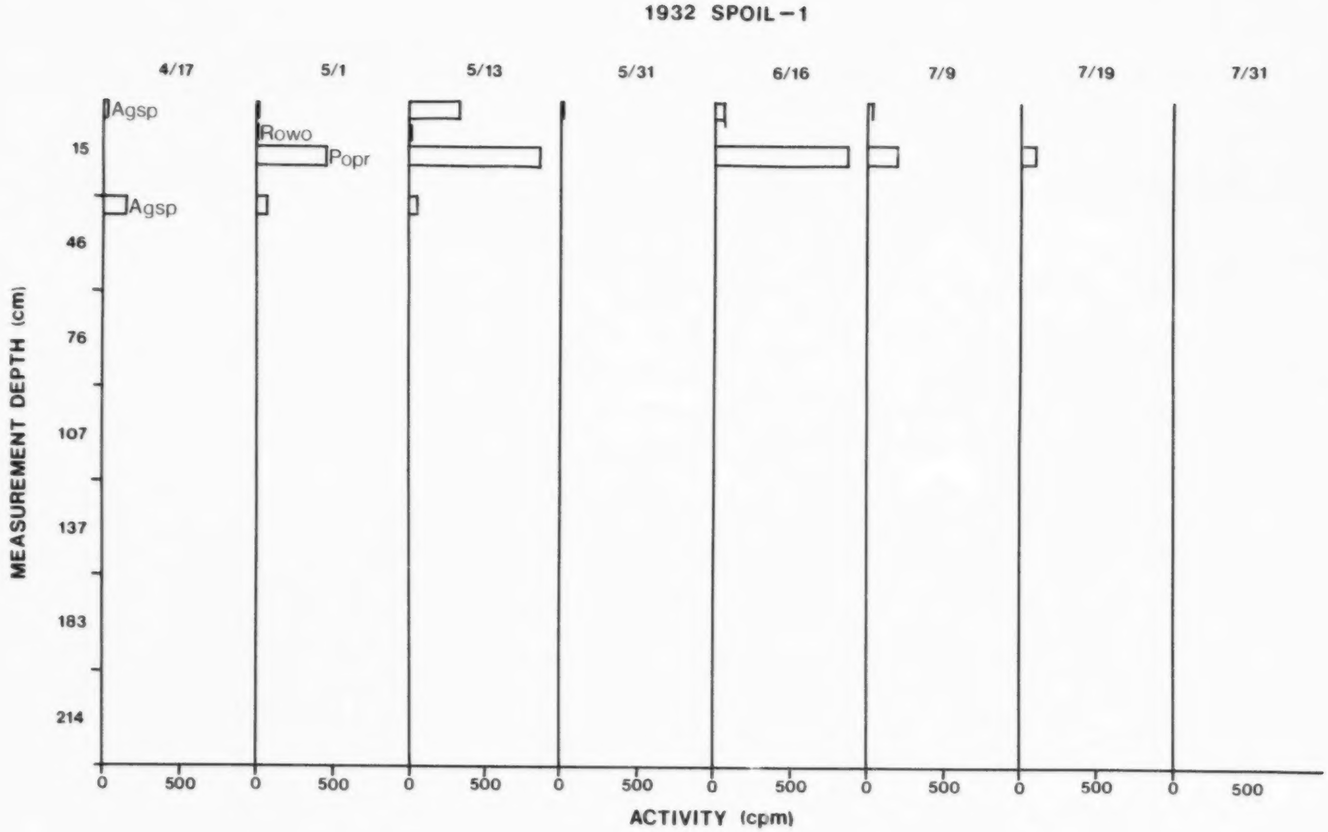

Fig. C-7. *In situ* plant radioactivities on 1929-10 spoil at Colstrip study area - replication 1, 1977.

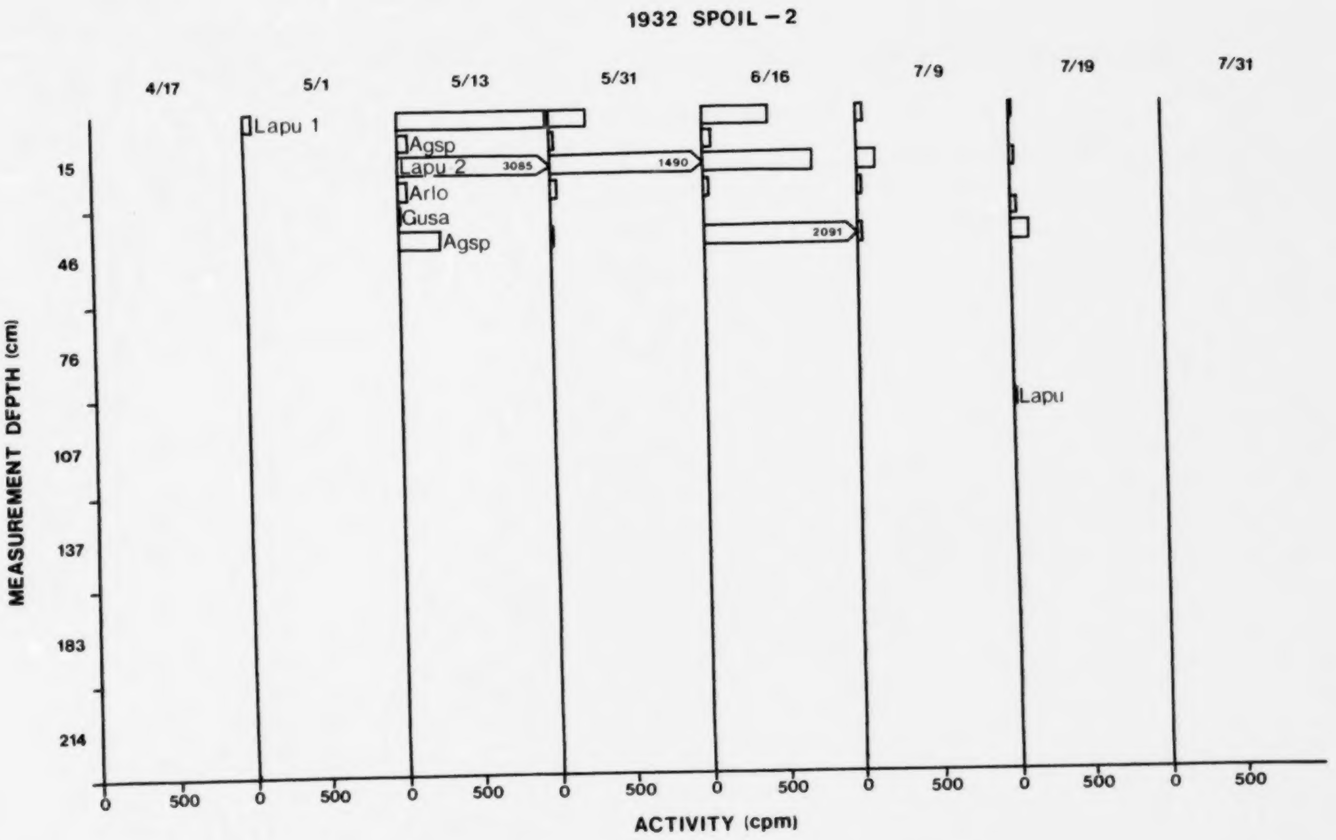

Fig. C-8. *In situ* plant radioactivities on 1929-10 spoil at Colstrip study area - replication 2, 1977.

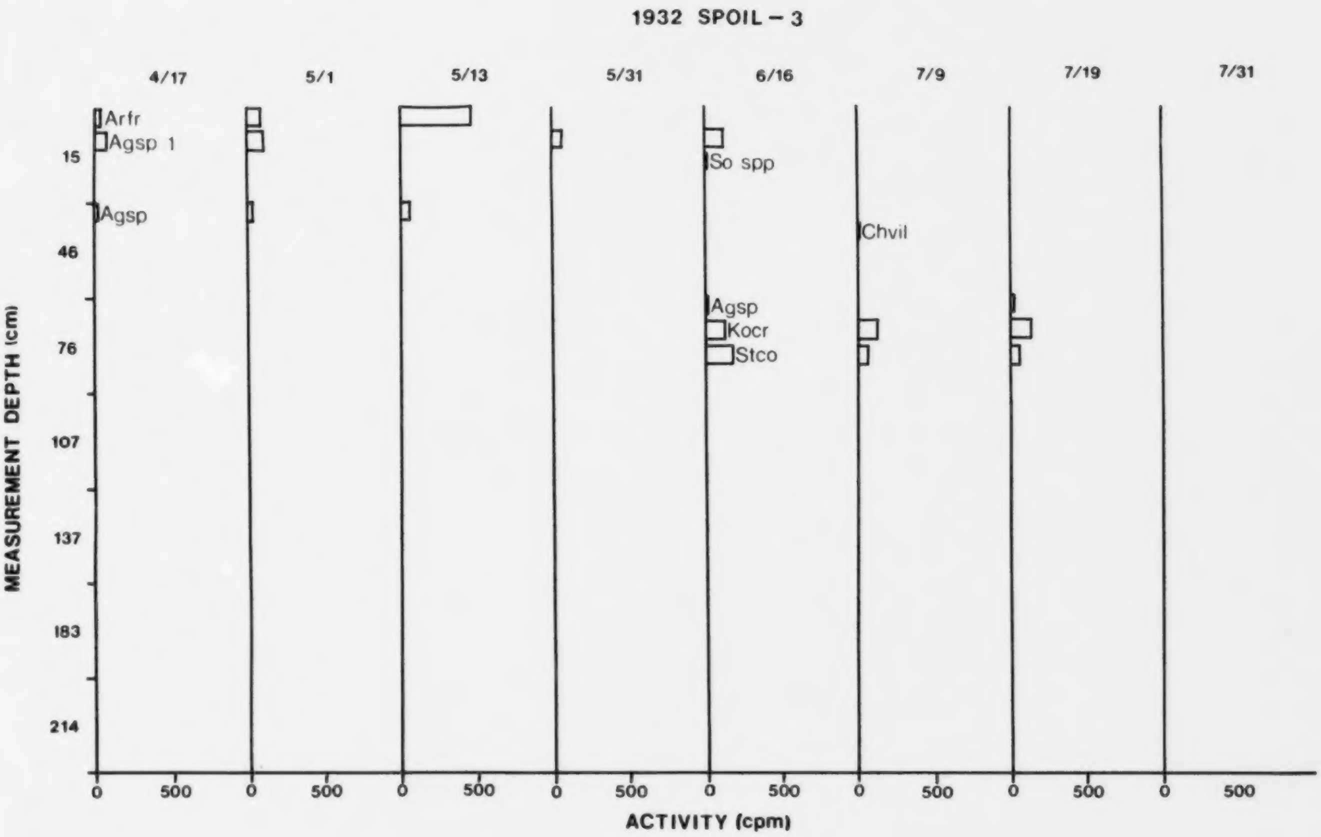

Fig. C-9. *In situ* plant radioactivities on 1929-10 spoil at Colstrip study area - replication 3, 1977.

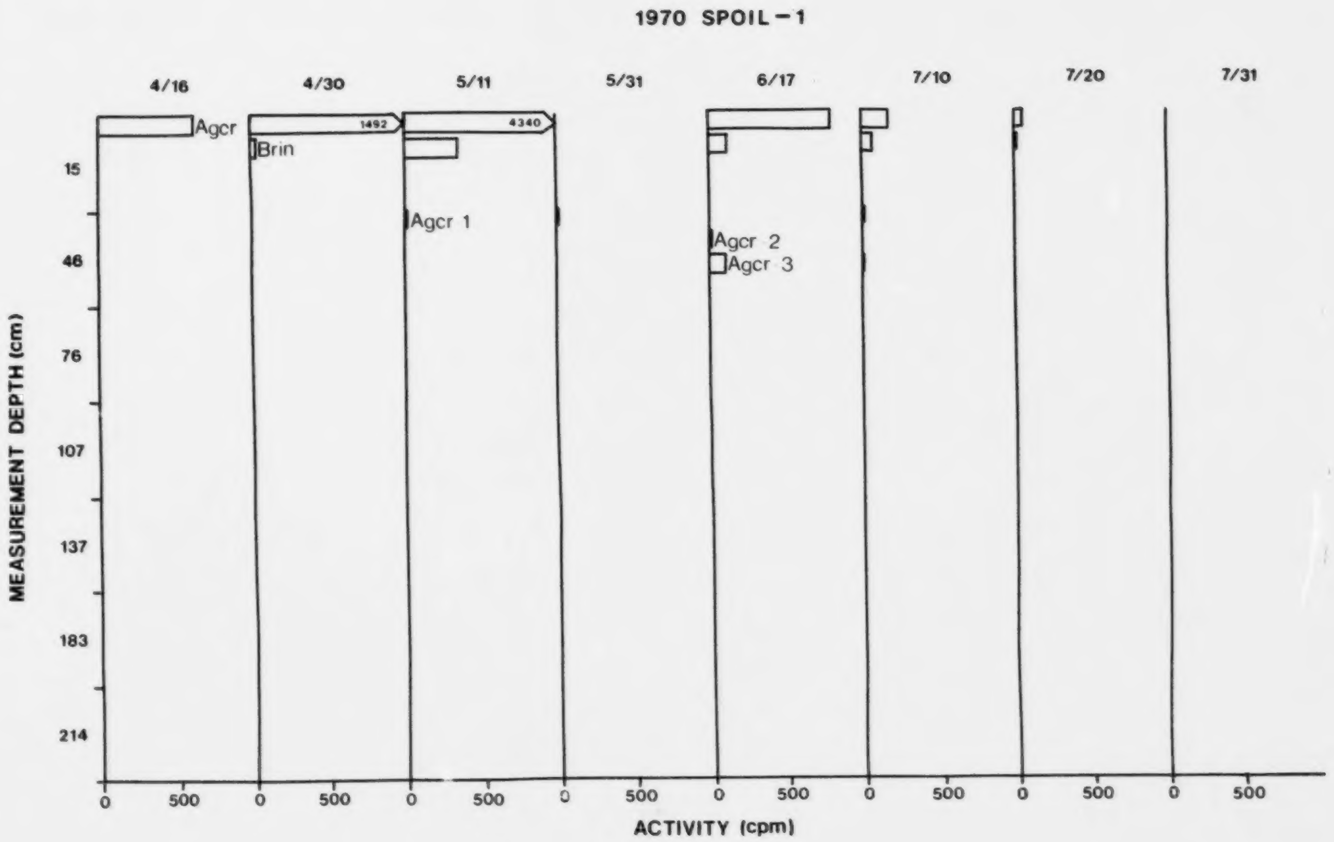

Fig. C-10. *In situ* plant radioactivities on 1970-15 spoil at Colstrip study area - replication 1, 1977.

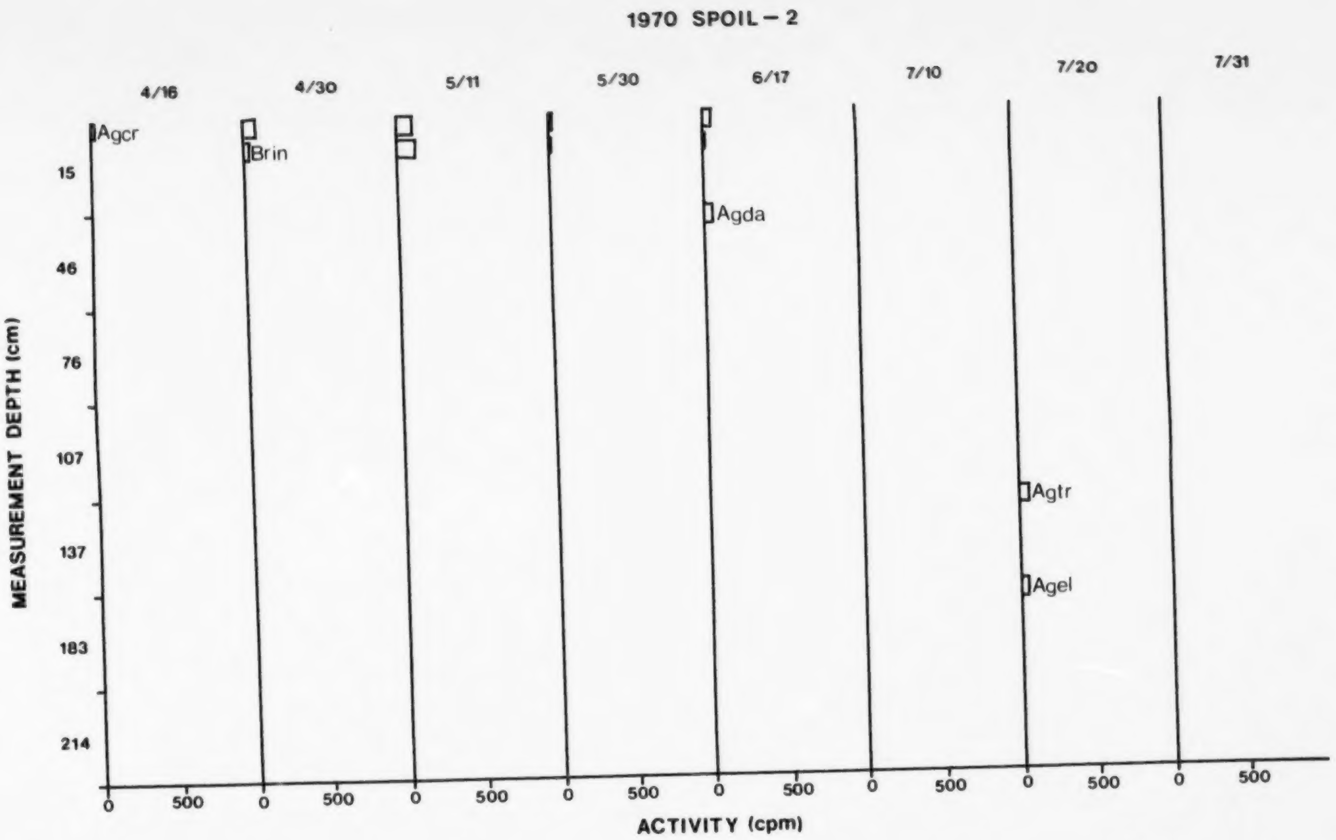

Fig. C-11. *In situ* plant radioactivities on 1970-15 spoil at Colstrip study area - replication 2, 1977.

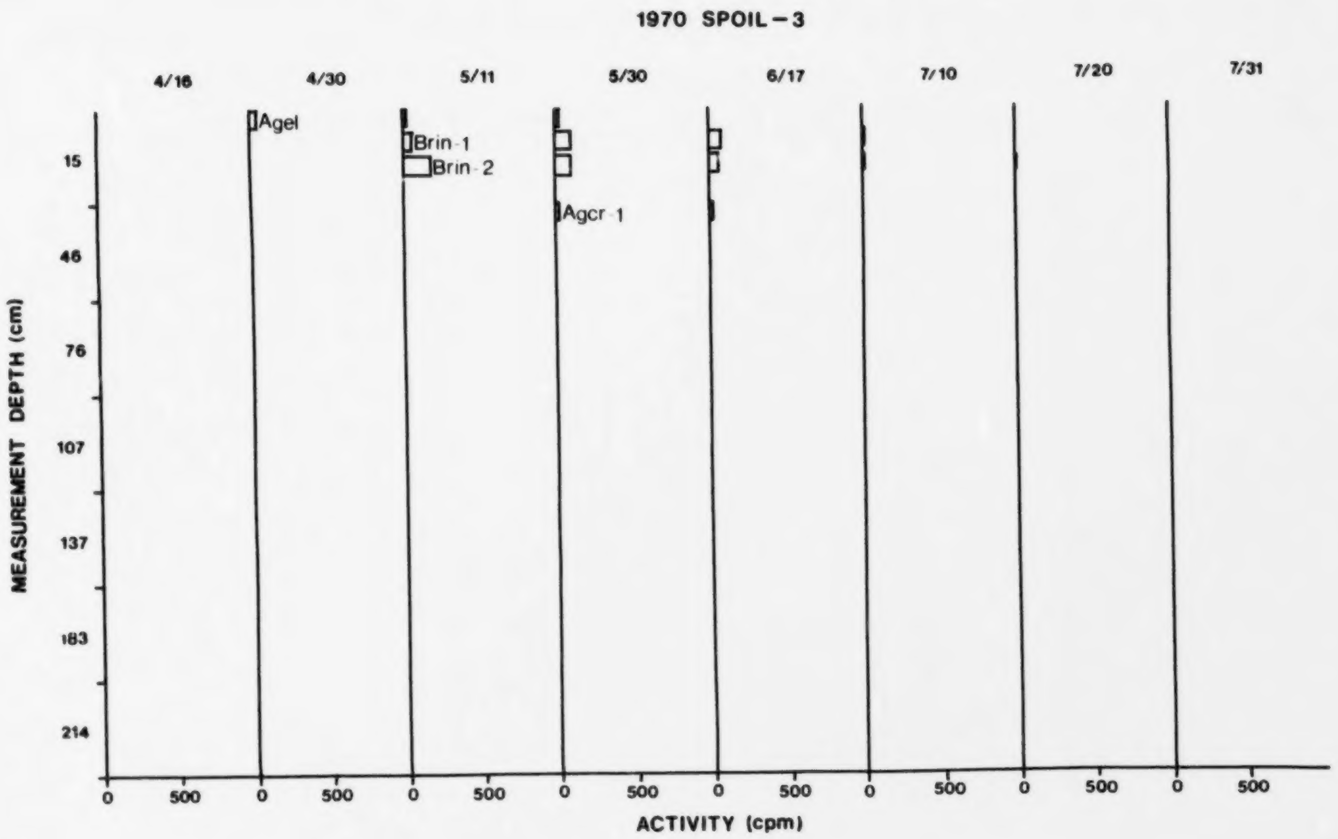

Fig. C-12. *In situ* plant radioactivities on 1970-15 spoil at Colstrip study area - replication 3, 1977.

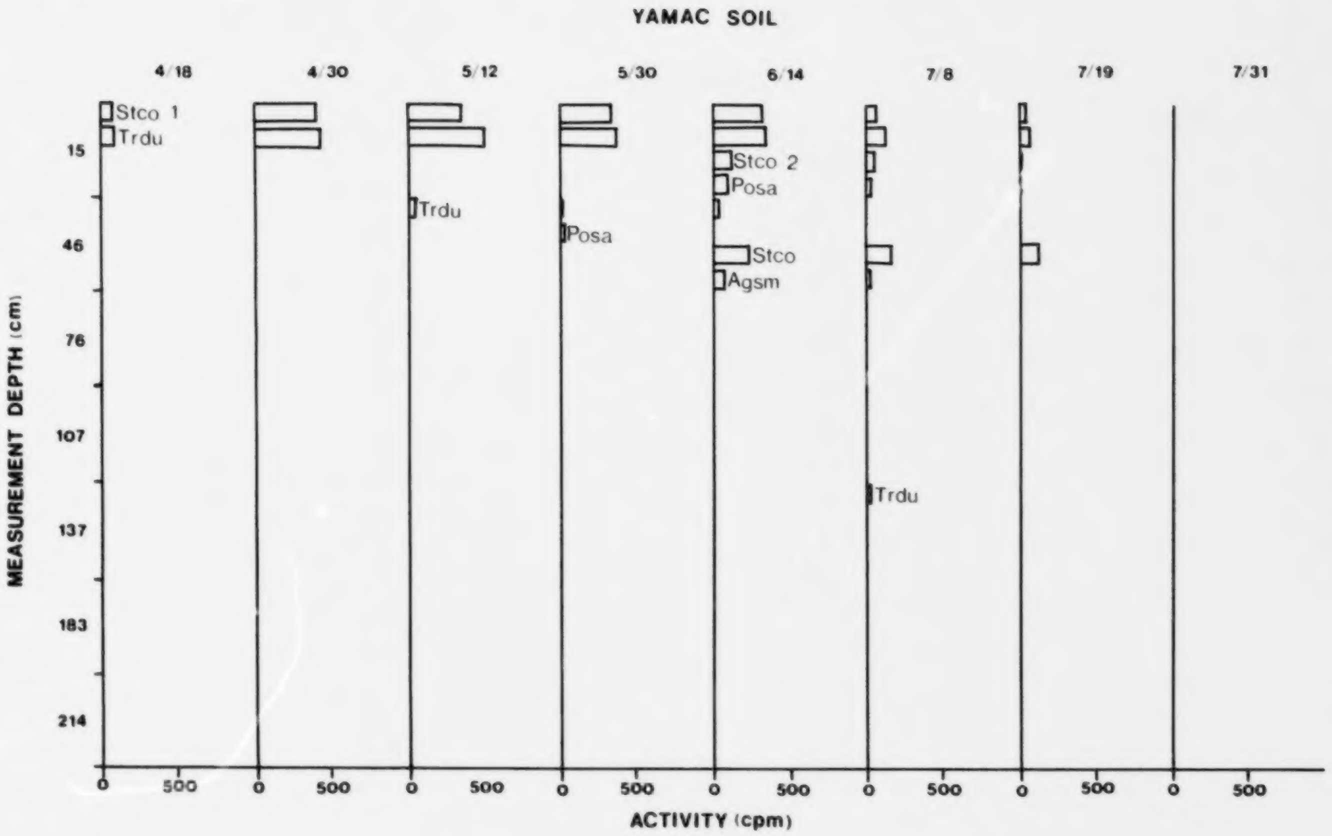

Fig. C-13. *In situ* plant radioactivities on Boxwell-2 undisturbed soil at Colstrip study area in 1977.

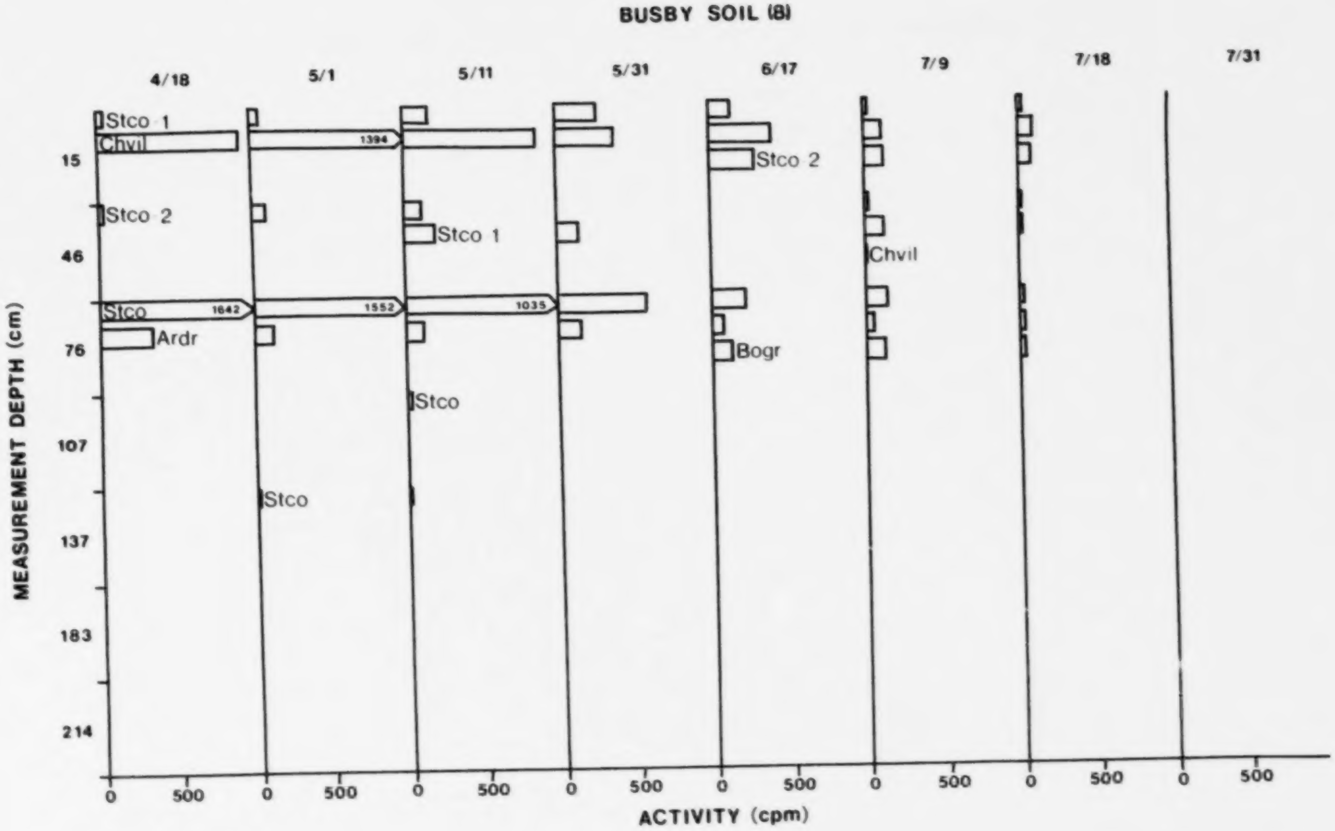

Fig. C-14. *In situ* plant radioactivities on Chinook-8 undisturbed soil at Colstrip study area in 1977.

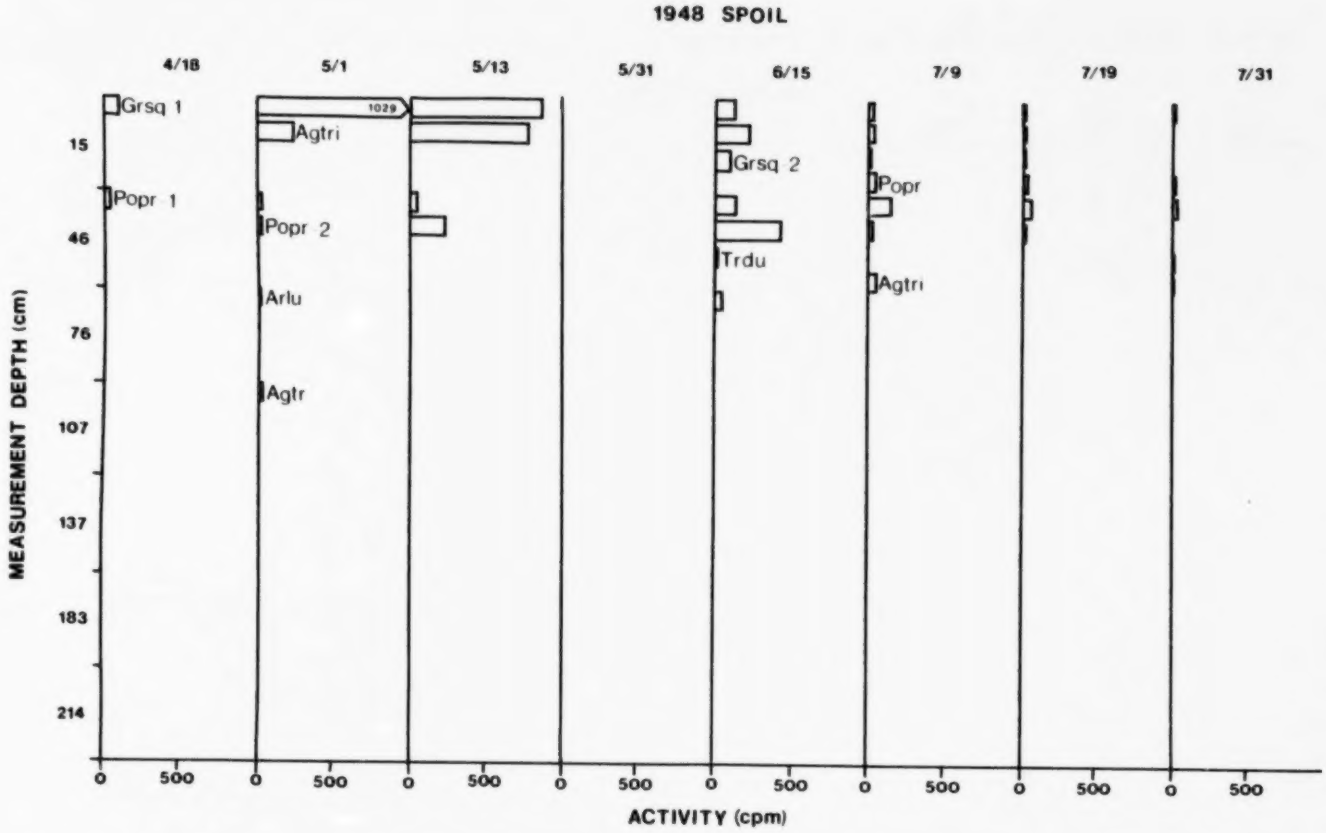

Fig. C-15. *In situ* plant radioactivities on 1948-3 spoil at Colstrip study area in 1977.

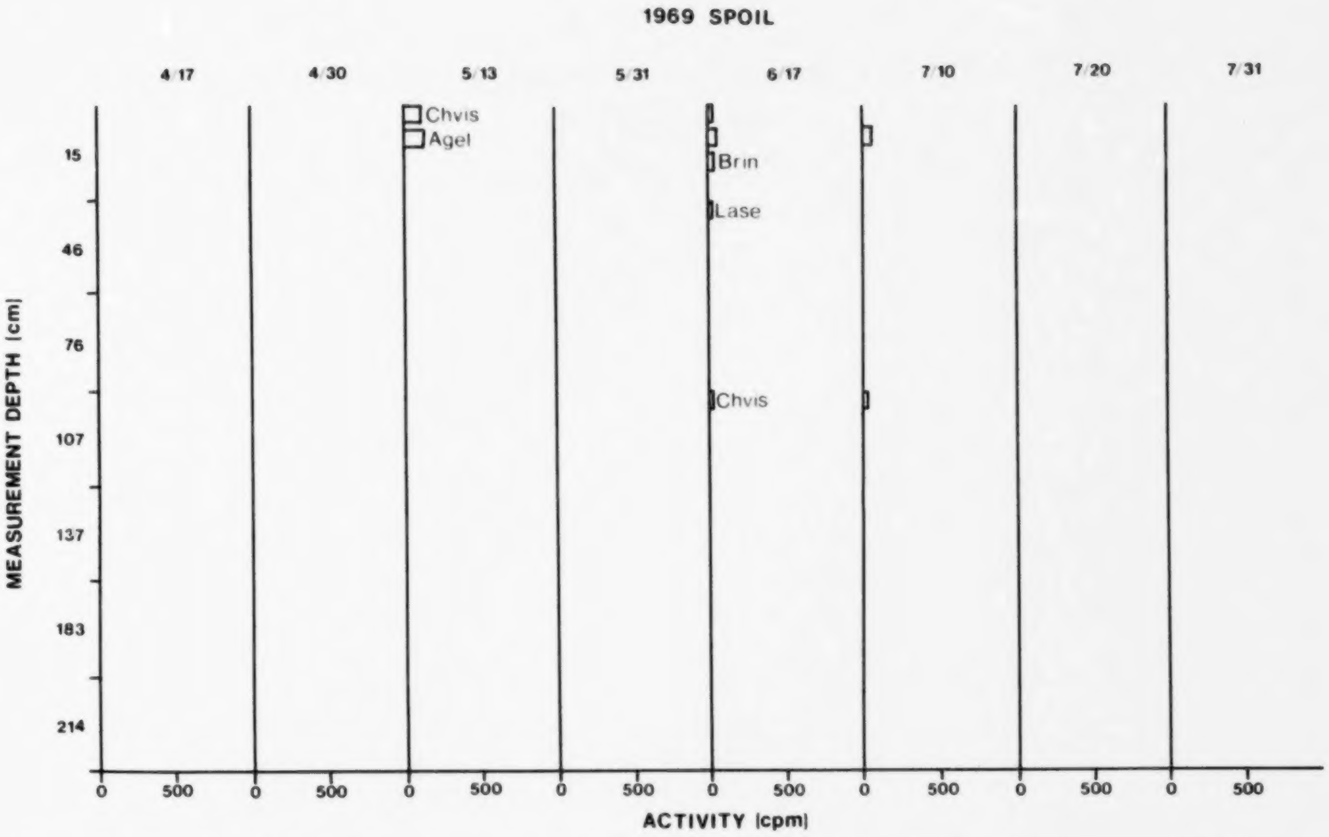

Fig. C-16. *In situ* plant radioactivities on 1969-14 spoil at Colstrip sty area in 1977.

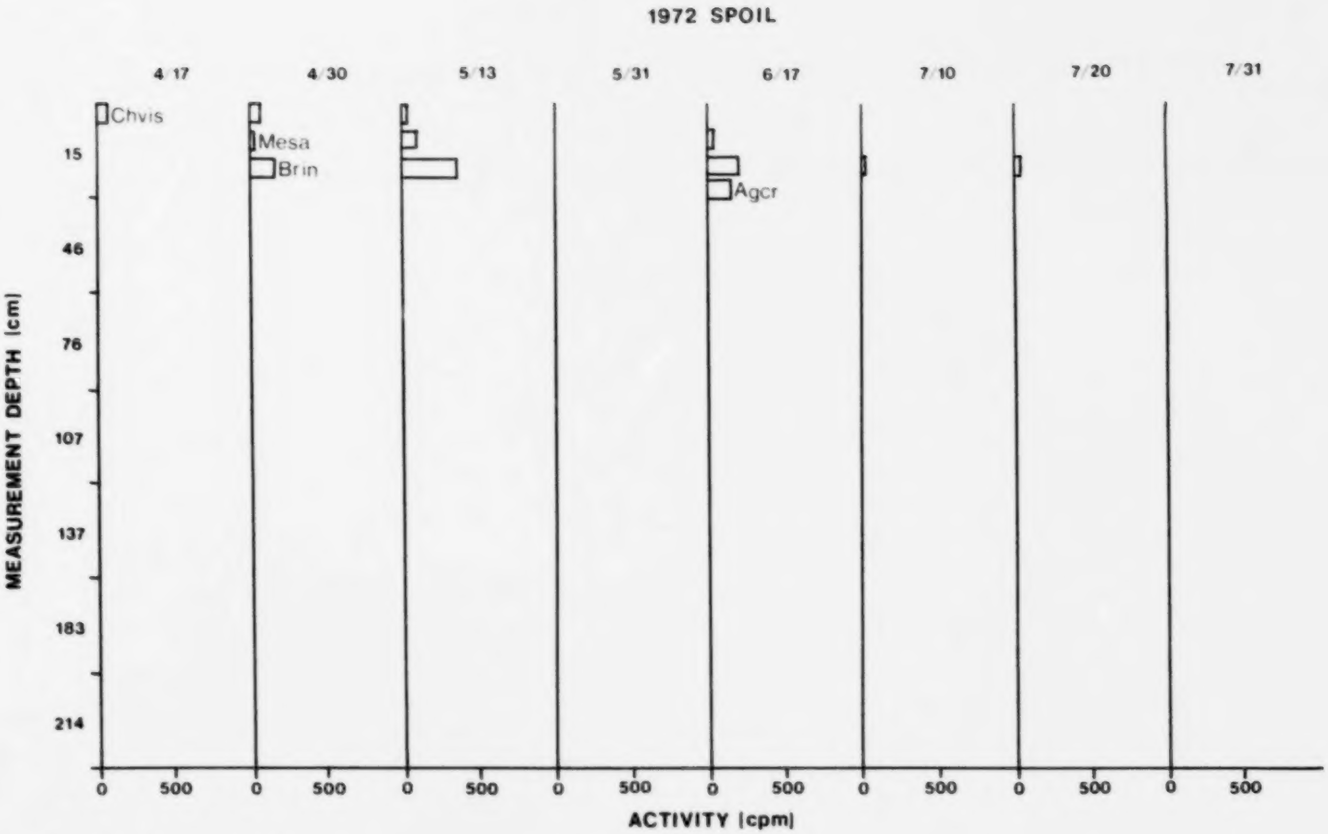

Fig. C-17. *In situ* plant radioactivities on 1972-13 spoil at Colstrip study area in 1977.

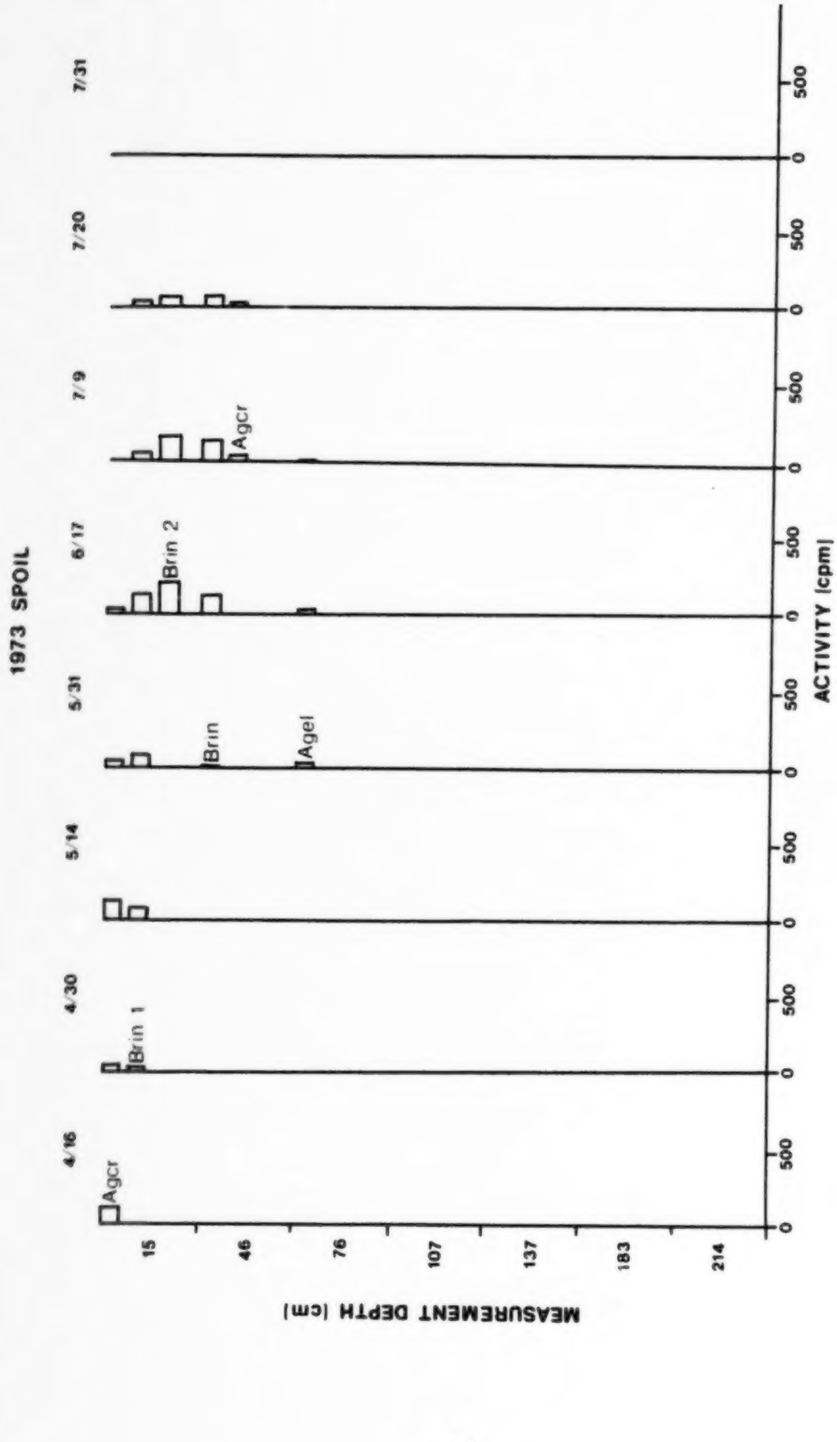

Fig. C-18. *In situ* plant radioactivities on 1973-12 spoil at Colstrip study area in 1977.

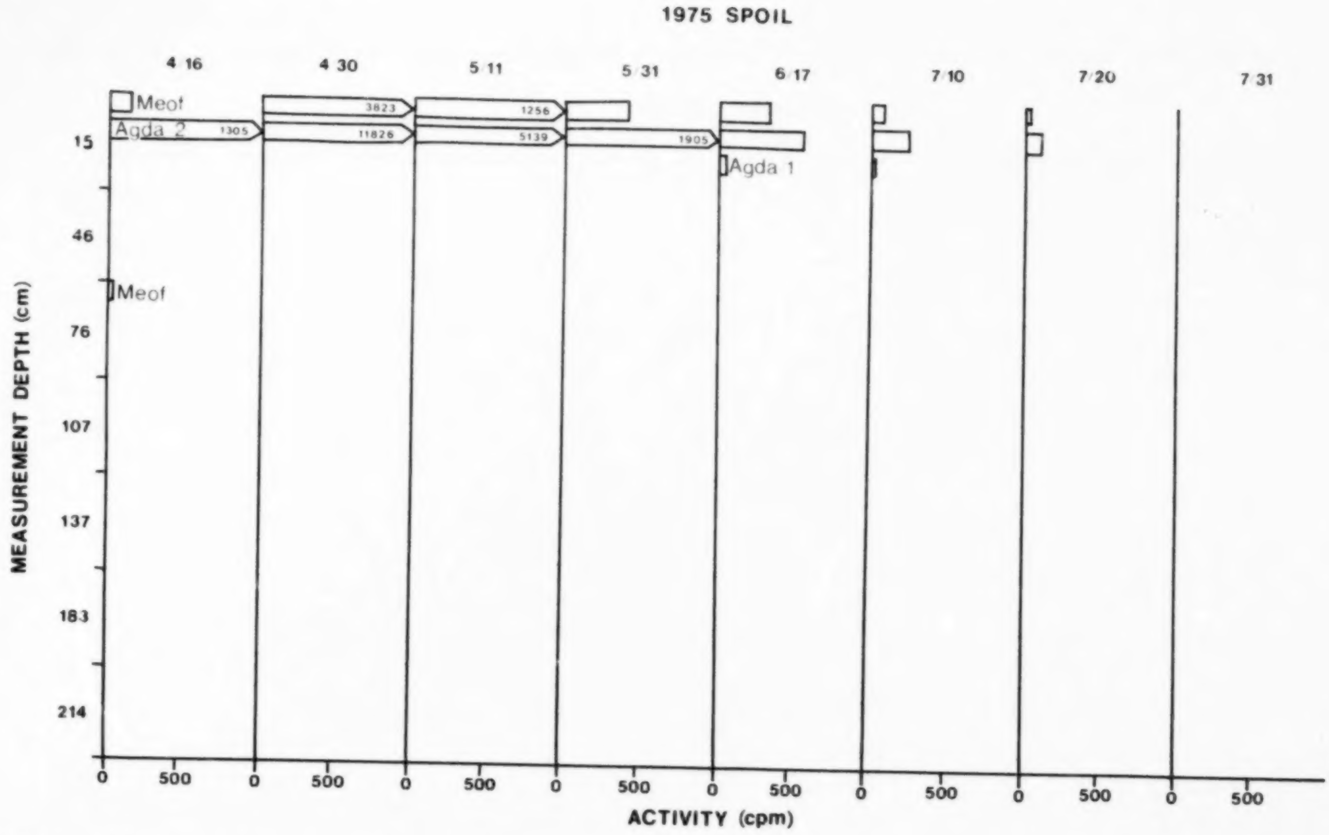

Fig. C-19. *In situ* plant radioactivities on 1975-11 spoil at Colstrip study area in 1977.

Table C-1. Plant activity index (PAI) values obtained from native range soils near Colstrip, Montana.

Site	Injection Depth (cm)	Species	1976			Injection Depth (cm)	Species	Rep	1977						
			6/27	7/16	8/9				4/17	5/1	5/13	6/15	7/9	7/19	7/31
CHINOOK-1	15	STCO	282	306	-245	15	TRDU	1	11	31	66	174	-57	701	-507
	46	STCO	126	444	-248		KOCR	1	449	32	235	339	97	-72	-104
	76	STCO	11				STCO	1				9	132	-147	-655
		AMPS	25	27			STCO	1				8	-47	57	-27
	107	KOCR	34	-11			NSPP	2		28	156	431	-3	132	-674
		KOCR	3	3			STCO	2	14	25	157	229	677	4827	1236
	137	MEOF	25	-15	30		CANO	2				36			
		ASCI	14				STCO	3	6	39	113	306	61	-607	463
		KOCR	43				TRDU	3	11	36	309	103	-77	-126	-100
	183	KOCR	21				ARFR	3		9	59	263	-63	-242	211
		CIUN	5				STCO	3				86	143	-446	36
		TRDU	4				POSA	3				85	-46	-72	-14
		STCO		4		46	ARFR	1				2	-19	-11	-6
							STCO	1				47	-20	1963	-706
							LEDO	2		76	2	-53	100	404	-510
							STCO	2			3	840	214	3686	-605
							STCO	2			86	171	-11	-392	66
							STCO	3				1	-12	28	244
							BOCR	3				-7	9	-72	-21
						76	TRDU	1				8	134	1087	-82
							STCO	2				39	791	2149	452
							KOCR	3				9	-68	11	0
						107	STCO	1				7	108	238	-136
							STCO	3				24	724	3000	1823
						137	STCO	2			1	-11	-2	-1	-1
BOXWELL-2	15	ARLO	152		12										
		BRTE	76	306											
		TRDU		15	-25										
	46	BRTE	22	25											
		POSA	13												
		ARLO		70											
	76	ARLO	8		1										
		BRTE	5	36	25										
RIEDEL-6	15	STCO	194	525	-312										
		CHVIL			4										
	46	PEPU	170	446	450										
		CHVIL	1												
		KOCR	10												
		POSA		13	-4										
	76	PEPU	187	274											
		PSAR	31	304											
		STCO			2										
CHINOOK-8	15	BRJA	35			15	STCO		3	6	51	40	-76	153	
		ARLO		11			HVIL		102	168	2	85	-59	251	
		CALO			15		STCO					15	44	142	
	46	CHVIL	53	170	80	46	STCO		3	-2	26	24	89	-912	
		CALO		19	12		STCO			6	28	-19	3	73	
	76	CHVIL	106	-3	-50	76	STCO		180	125	34	6	110	-738	
		AMPS		8	5		ARDR		37	-11	12	15	44	70	
	137	ARDR		9			BOGR						194	-477	
		GALO			8										

Table C-2. Plant activity index (PAI) values obtained from old mine soils near Colstrip, Montana.

Site	Injection Depth (cm)	Species	1976 6/27	1976 7/16	1976 8/9	Injection Depth (cm)	Species	Rep	1977 4/17	1977 5/1	1977 5/13	1977 6/15	1977 7/9	1977 7/19	1977 7/31
1948-3						15	GRSI		11	200	87	-19	-28	-5	-69
							GTRI			15	239	23	-65	-119	-126
							GRS2					4	-24	-7	-72
							POPR						2	-90	25
						46	POPR		4		14	51	180	-380	38
							POPR			1	84	134	-241	20	-101
							AGTR						2	-291	-58
						76	ARLU					6	-20	-11	-6
1928-5	15	ARDR	13	24											
	46	ARDR	43	182											
	76	ARDR	1	106	-23										
		PSAR	6	12											
	107	ARDR		10	0										
1928-7	15	ARCA	69	34	4										
		ARDR	70	74											
	46	ARDR	12	-2	38										
		MEOF	22												
		AMPS			2										
	76	MEOF		3	31										
	137	ARDR		1	83										
		STCO		1											
		AMPS			7										
1928-9	15	ASCI	1	9	-5										
		PEPU		29											
	76	MEOF		123											
		AMPS		2	11										
		STCO			1										
	107	ARDR	66	-6											
	137	STCO	1	4											
		ARDR		2	15										
1929-10	15	ROWO	20	86	-41	15	ROWO	1			1				
	46	AGSP	3	20			AGSP	1	2		123	62	-2	-123	
		MEOF	11	26			POPR	1		31	226	252	-195	-303	
	76	AGSP	20	-8	-4		AGSP	2			4	50	-38	-70	
		MEOF		3	9		LAPU	2		4	353	405	-233	-147	
	107	AGSP	1		2		LAPU	2			179	36	-260	-653	
		MEOF		7			ARLO	2			3	13	8	-99	
		LASE	8				ARFR	3	4	12	152	-32	-9	-5	
		AGDA		19			AGSP	3	8	12	-22	124	-92	-48	
	137	MEOF		15		46	AGSP	1	18	-2	4	-3	-1	-1	
							GUSA	2						4	
							AGSP	2			16	2696	-1480	-1138	
							AGSP	3	2	2	15	-3	-1	-1	
						76	STCO	3				9	26	269	
							KOLR	3				6	218	563	

Table C-3. Plant activity (PAI) values obtained from new mine soils near Colstrip, Montana.

SITE	INJECTION DEPTH(cm)	SPECIES	1976			INJECTION DEPTH(cm)	SPECIES	REP	1977						
			6/27	7/16	8/9				4/17	5/1	5/13	6/15	7/9	7/19	7/31
1975-11	15	AGSM		55	-21	15	MEOF		18	599	-370	28	-86	-234	
	46	SAKA		495			AGDA					2	5	-132	
		AVFA		5	-2		AGDA		165	1491	-273	-174	136	-348	
						76	MEOF		3	-2	-1				
1973-12	15	BRJA	4			15	AGCR		13	-1	33	3	-25	-13	
		AGCR	13	65	-24		BRIN			2	17	40	42	-119	
	46	AGCR			5		BRIN					10	209	-418	
		BRJA	1			46	BRIN					92	221	-118	
							AGCR						2	-106	
						76	AGEL				1	26	-11	-40	
1972-13	15	MESA	242	27	209	15	AGCR		7	6	1	54	-122	-63	
		AGCR	3		7		MESA			1	27	6	-25	-13	
	46	MESA	3	14	4		BRIN			11	90	49	-130	150	
	76	MESA	1	10											
		AGCR	3	4	-4										
		BRIN			1										
	107	BRIN	2												
	137	AGCR	2												
1969-14	15	MEOF		22	3	15	CHVI				6	3	-21	-11	
		CHVI		5	-12		AGEL				8	11	-85	-255	
	46	CHVI		7	-7		BRIN					1	-19	-10	
		BRIN		8	-18	46	LASE					1	-14	-7	
	76	CHVI		9		107	CHVI					1	38	-15	
		AGEL		19											
	107	AGEL		2	-4										
		CHVI		4											
	137	AGEL		12											
		CHVI		7	7										
		BRJA		13	-31										
	183	CHVI		3											
1970-15	15	MEOF	18	0	58	15	BRIN	1		2	128	15	76	-383	
		AGCR	15	56	9		AGCR	1	78	175	1319	25	-226	-545	
	46	STCO	11				BRIN	2		2	41	-4	-2	-2	
		MESA	16	161	21		AGCR	2	2	10	24	59	-39	-20	
		AGCR	14		1		BRIN	3		1	16	41	-50	-26	
		BRIN		10	6		AGEL	3		2	-1	-11	-2	-1	
	76	AGCR	2		2		BRIN	3			11	20	-31	-23	
		AGEL	3	10	16	46	AGCR	1				5	-66	-52	
		MESA	2	46	33		AGDA	2				3	-39	-21	
	107	AGCR			2	137	AGTR	2						2	
		AGEL		1	45	183	ACEL	2						1	
	137	DOSA	2												
		BRIN			1										
	183	STCO			3										
		AGEL			3										